CANADIAN FISHERIES EXPEDITION, 1914-15.

The Hydrodynamics of Canadian Atlantic Waters

BY

W. J. Sandström.

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THE HYDRODYNAMICS OF CANADIAN ATLANTIC WATERS.

By J. W. Sandström.

PREFACE.

Dr. Johan Hjort has entrusted me with the task of working up, in dynamic form the results of his hydrographical observations in the Canadian Atlantic waters. It has been a great pleasure to me to undertake this work, as the observations, being restricted to the upper strata of dynamic interest, and with the consequent limitation in point of time, may be regarded as almost simultaneous; a feature of great importance when dealing dynamically with the material. In addition to this, the area in question is a most interesting one, presenting as it does a well-defined mass of water acted upon by various and very considerable forces. In the course of the work, valuable assistance has been afforded me by Mr. Paul Bjerkan's clear and concise report of the expedition, Mr. Thorolf Rasmussen's excellent draughtmanship in the elaboration of my rough pencil sketches, and Mr. W. J. A. Worster's translation into English of my hastily compiled Swedish text. Without such co-operation, I should scarcely have been able, in the scanty leisure left me by my official duties and other obligations, to carry through the work at all; as it is, I hope that the following pages may prove of some value, not only in discussion of the observations in question, but also as contributing to the general comprehension of various phenomena in the oceans of the world, in regard to which the conditions prevailing in Canadian waters may be taken as affording analogy and illustration.

The "Survey of Tides and Currents in Canadian Waters," "The Currents in the Gulf of St. Lawrence," and other publications kindly placed at my disposal by Dr. Hjort, contain a mass of most valuable observations as to the movement of the surface water in the gulf of St. Lawrence and adjacent waters.* A good indication of the reliability of these observations is the fact that the popular but erroneous theory of currents due to the action of wind, has here been abandoned. Instead of this, we frequently find the correct observation that a current may arise, or increase in force, some time before the appearance of a storm, such currents being as a rule in a direction contrary to that of the coming wind. These phenomena, which are explained by Bjerknes' circulation theory, give the observer generally an impression that the water in the sea has a very remarkable and unexpected tendency to opposition against the forces striving to act upon it. The usual primitive conception as to the laws which govern movement in liquids will not suffice to explain such paradoxical phenomena; it will be necessary to introduce new ideas, for the proper comprehension of which a considerable amount of mathematical knowledge will frequently be required. On the other hand, it seemed to me of the highest importance that the interested observers in the Canadian Atlantic waters, and also in other parts of the globe, should be able to familiarize themselves with these new principles, and I have therefore endeavoured to get around the mathematical difficulties as far as possible by extensive use of graphical illustrations, and by reference to well-known

* This series of valuable publications, embraces the results of many years' investigations by Dr. W. Bell Dawson, D.Sc., F.R.S.C., etc., head of the Dominion Tidal Survey, Ottawa, and the staff under his direction.

principles, in particular the Archimedean, which, in addition to being generally understood, is simple and easily comprehensible in itself. I have, moreover, in order to exemplify these principles, given reports of some experiments and also taken some examples from the atmosphere when the hydrographical facts were insufficient. Such limitation and simplification will, I trust, render these complicated yet interesting theories accessible to a wider circle among those at all occupied with marine phenomena.

The following pages open with a short report of Dr. Hjort's observations. These naturally form the foundation upon which the whole of the subsequent discussion is based, as without knowledge of the conditions prevailing down in deep water, it would be impossible to explain the phenomena which take place in the sea, or even those apparent at the surface. The next sections will be devoted to my own explanation of the questions concerned, in the simplified manner above mentioned, leading up to an exposition of that part of Bjerknes' theory which directly applies to conditions in the sea, further the changes into different kinds of the energy in the sea and as summary an application of the laws found on the Canadian Atlantic waters.

I.—GEOGRAPHICAL CONDITIONS OF THE AREA OF INVESTIGATION.

I have before me a chart of the area in question, with numerous soundings, presenting a detailed survey of the bathymetrical conditions. In order to obtain some idea as to the dimensions of this marine basin, I draw out on the chart a system of parallel lines, at intervals of 100 km., each line being again divided up into lengths of 100 km., (fig. 1). At the points thus marked off, I draw short lines indicating the depth, these latter being perpendicular to the original system of parallels. By inserting the intermediate depths according to the chart, vertical sections are obtained for every 100 km. throughout the entire area. (Fig. 1.)

In marking off the depths, I endeavoured at first to adhere to the same scale as that for the horizontal dimensions of the chart, but found the lines thus drawn too short; I therefore multiplied them by ten, so that the lines for vertical dimension were drawn to a scale ten times that of the horizontal. Even this, however, proved insufficient, and I found it necessary to magnify them 100 times in order to render them reasonably legible.

In order, then, to obtain a correct idea as to the bathymetrical conditions within the area investigated, we must imagine the depth lines reduced to one-hundredth of the length shown in the figure. It now becomes apparent, that the vertical dimensions are extremely small in comparison with the horizontal. Drawn to the scale of the chart, the greatest depth within the area would appear about equal to the thickness of the paper on which it is printed. And if we should attempt to draw a vertical section across the area, maintaining the correct proportion between depth and horizontal extent, the result would be merely a line and this moreover in the shallower portions, so fine as to be invisible to the eye.

If we were to make an exact model, on a reduced scale, of the area in question, it would appear, at a first glance, to be perfectly flat. And on attempting to "fill" it with water to a level answering to that of the sea, as a first step to experimental reproduction of the actual hydrographical phenomena, even this would be found practically impossible, owing to the surface tension of the water. So thin a layer would either wet the entire surface of the model or leave dry patches here and there without regard to level. To obtain a basin suitable for the purposes of such experiment, the depth would have to be magnified 1,000 times in proportion to the horizontal extent.

This disproportion between the vertical and horizontal dimensions should be constantly borne in mind throughout the discussion of the sections dealt with in the following pages.

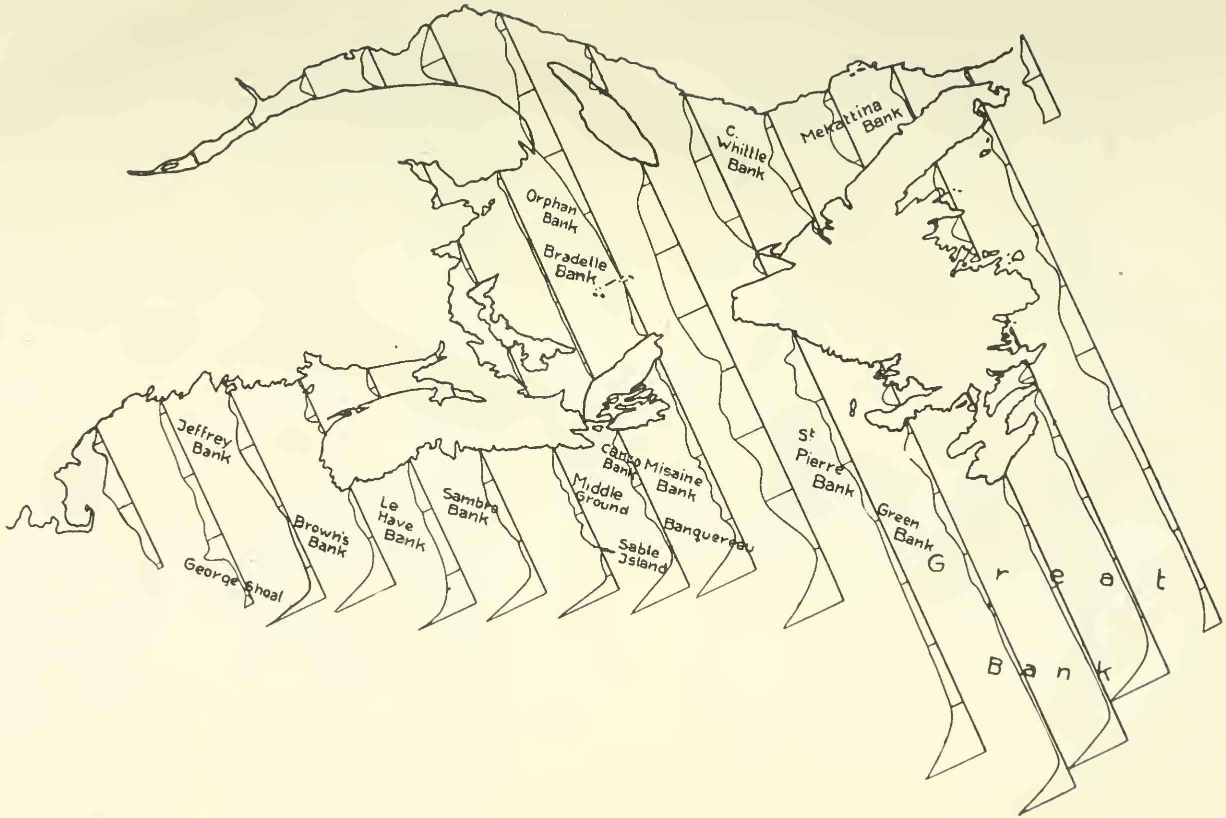


Fig. 1. Map, showing the dimension of the area investigated. The distance between the sections and the distance between the verticals in each section amounts to 100 kms. In relation to the horizontal dimensions the depths are very insignificant, the largest depths are about represented by the thickness of the paper used for printing. In the sections the depths are therefore enlarged 100 times, in relation to the horizontal dimensions, and the largest depth toward the Atlantic slopes drawn in the map represent 1000 m.

Let us now make a mental experiment. We imagine, in the centre of the area of investigation, e.g., on Cape Breton island, a high tower, built in the form of a gasholder. To the centre of the roof, on the inner side, is fastened a fine but strong cord, at the lower end of which, reaching nearly to the floor, a heavy weight is attached, forming a pendulum. This pendulum is set in motion, and the plane in which it moves marked off by a line drawn on the floor at certain intervals of time. It will then be found that the plane in question revolves in the same direction as the hands of a watch placed with the dial upwards. The rate of progress is about 11° per hour; i.e., the plane of the pendulum would make one complete revolution in thirty-three hours, supposing that the pendulum itself could be kept in motion for that time. Fig. 2 shows the course traversed by the plane in the space of twenty-four hours.

Fig. 2.—The rotation of the pendulum plane during 24 hours by a Foucault's pendulum experiment on the Newfoundland area.

The cause of this phenomenon is as follows: The plane in which the pendulum oscillates does not, as a matter of fact, revolve at all; what does revolve is Cape Breton island and its surroundings, which turns with the earth's rotation about its axis. Similarly, in our pendulum experiment, it is the tower which turns, at the rate of one complete revolution in thirty-three hours, while the true plane of oscillation for the pendulum remains unchanged. The revolution of this plane is thus only apparent, and, correctly interpreted, means simply that the whole of the Canadian Atlantic area is rotating, at what, in consideration of its enormous extent, must be regarded as a very high rate of speed. The direction of this rotary movement is counter-clockwise, i.e., the reverse of the movement made by the hands of a watch dial upwards; the rate of speed

$$\omega = \omega_0 \sin \varphi \quad \ldots\ldots\ldots\ldots \quad (1)$$

where φ is the latitude, ω_0 the angular velocity of the earth about its axis, ω the angular velocity of the surface of the earth at a latitude amounting for the area in question to about three-quarters of a revolution in the course of the twenty-four hours.

Fig. 3 shows the position of the Canadian Atlantic area at a moment of starting, after 6 hours and after 12 hours. At the moment of starting, we have drawn in the conventional manner N upwards, S downwards, with E on the right and W to the left. After the lapse of six hours, these points of the compass will have shifted 65°, and after the lapse of 12 hours, 130°, to the left. The Gaspé and Cape North currents, which in the first illustration are seen moving towards the right, continue their movement in this direction, despite the rotation of the substratum, thus curving round Gaspé and Cape Breton island, as shown in the two following diagrams. On the other

hand, the current passing cape Ray commences towards the left, and in this direction, owing to its inertia, it still continues, although the substratum is under rotatory movement. Consequently, the current is seen to curve round the southwestern point of Newfoundland. This point is, however, so sharp, that the current cannot turn there, to enter St. George's bay, but does not become perceptible until reaching the Bay of Islands, and is then very distinctly apparent along the coast as far as Rich point. Owing to the same cause, the Labrador current turns up into the fjords along the whole of the east and southeast coasts of Newfoundland; hence the numerous shipwrecks in those waters. " Seamen should be on their guard against an indraught among the Fago and Wadham islands into Sir Charles Hamilton's sound, Bonavista, Trinity and Conception bays.......On the southeast coast, so many wrecks have occurred, especially near cape Pine and St. Shot's cove, that the compass has been considered to be subject here to local disturbance, but special examination has shown that this is not the case, and that these disasters were mainly attributable to the effect of the currents ". (Sailing directions of the North American coast).

The rotation of the earth about its axis, then, gives to the ocean currents an apparent tendency to turn off towards the right. As a matter of fact, the actual tendency of the water is owing to its inertia most emphatically towards direct forward progress, but the continual rotation of the ocean basins and the coasts towards the left (Fig. 3) makes the currents appear as persistently veering off to the right.

The reader should, throughout the following pages, continually bear in mind the three points which have been emphasized above, viz., the insignificance of the vertical dimension in the sea when compared with the horizontal, the continual rotary movement of the basins towards the left (in the northern hemisphere) due to the earth's rotation, and the obstinacy with which sea water opposes the action of external forces.

2. THE HYDROGRAPHICAL OBSERVATIONS.

Plate I shows the position of the hydrographical stations. Sections I-IX, carried out during the time between May 29 and June 26, 1915, give the hydrographical conditions in spring, and sections X-XX, July 21 to August 12, 1915, the same for summer. In addition, the separate stations, 1, 2, 3, and 4 in the gulf of St. Lawrence belong to the spring cruise, and stations 27, 28, 54, 58, and 59 in the same water to the summer cruise.

Plate I shows likewise the bathymetrical conditions in the area investigated. With regard to those, the remarks about Fig. 1 should be borne in mind, i.e., that the depths are extremely slight in proportion to the horizontal distances. The chart presents a fairly detailed picture of the bottom contour. The position of the banks, and their extent, should particularly be noted, as also the regular contour of the Laurentian channel leading in from the Atlantic deep to the gulf of St. Lawrence, and the channels between the banks and the coast.

The following plates are based on the hydrographical material placed at my disposal by Dr. Hjort.

Plates II and III show the distribution of salinity as noted on spring and summer cruises, respectively. A water layer of less than 30 per cent salinity flows out at the surface between the Gaspé coast and Anticosti, filling the southern portion of the gulf of St. Lawrence, rounding cape North, Breton island, and proceeding thence south and southwest along the coast of Nova Scotia. Throughout its course, this layer is continually absorbing water from the subjacent strata, whereby its salinity is increased, until it ceases to exist as a coastal water. A surface layer of like character is also found during spring in the northern portion of the gulf of St. Lawrence. With increasing depth, and farther out to sea, the salinity is augmented in the manner indi-

Fig. 3.—The rotation of the Newfoundland area owing to the rotation of the earth.

cated by plates II and III. Not until the very outermost stations are reached, however, do we encounter true Atlantic water of over 35 per cent salinity.

Plates IV and V show the distribution of temperature during the spring and summer cruises. Particularly noteworthy is the enormous intermediate layer of temperatures below zero, which fills the whole of the gulf of St. Lawrence and a great part of the coastal zones outside. During the spring, it also extends far down towards the coast of Nova Scotia, but in summer the extent is somewhat less. Both above and below this intermediate cold layer, the temperature increases. During summer, we find a surface layer of comparatively high temperature. At the outermost stations, the warm Atlantic water is found.

The distribution of temperature and salinity, and the hydrographical conditions generally, have been thoroughly dealt with by Mr. Paul Bjerkan,[1] to whose work on the subject the reader is referred.

Given salinity and temperature, we can, by means of Martin Knudsen's tables, calculate σ_t and the specific volume; i.e., the volume in ccm. of a gramme of water. If we designate the specific gravity of the sea-water by ρ and the specific volume by v then we have

$$v = \frac{1}{\rho} \quad \dots\dots\dots\dots\dots\dots \quad (2)$$

If, for instance, σ=28,16, then ρ=1·02816, whence, according to formula (2), v= 0·97261. As, however, nearly all the values for specific volume within our area of investigation begin with 0·97, we may simplify matters by omitting this figure and multiplying the remainder by 10^5, whereby the specific volumes appear as whole numbers of three figures, and are thus far easier to manipulate. This is the more permissible, since we shall in the following only have occasion to reckon with differences of specific volume. Instead of $v = 0{\cdot}97261$, then, we write $v_1 = 261$, the equation indicating that a gramme of the water in question represents a cubic capacity of 0·97261 ccm.

In table 1, the first column shows the depths in metres at the points where water samples were taken, and the second column v_1 for the samples in question, calculated according to the method indicated above, from the last column in Bjerkan's hydrographical table. Plates VI and VII show the distribution of specific volume within the area investigated. It is greatest at the surface, decreasing downwards, which naturally means, that the lightest water lies uppermost, and the heaviest at the bottom. In the Gaspé current and the southern portion of the gulf of St. Lawrence, the specific volume is particularly great. The lines for like values of specific volume, the so-called isosteres, exhibit a far more horizontal and regular course than the isohalines and isotherms. In the upper water layers, the specific volume decreases rapidly with increasing depth, especially during summer, when the surface water is warmed by the sun; in the lower strata, however, the decrease takes place far more slowly.

Plates VIII and IX present a more detailed view of the course of these isosteres. For the deeper water layers, they have been drawn for each tenth unit of v, in the upper strata for each fiftieth. For general convenience of reading the isostere $v_1 = 500$ is here prominently shown.

[1] Paul Bjerkan: Results of the hydrographical observations made in the Canadian Atlantic waters by Dr. Johan Hjort during the spring and summer of 1915.

3. DYNAMIC IMPORTANCE OF THE ISOSTERIC SURFACES.

The stable position of the strata in these waters is in many respects characteristic of the movement occasioned therein. In order to make this clear, we may take a simple example. Fig. 4, let us say, represents a sea basin filled with homogeneous water, i.e. in which no isosteric surfaces occur, subjected at the surface to the action of wind blowing in the direction of the larger arrow. The water will then commence to circulate in the manner indicated by the small arrows, the current thus induced increasing continually as long as the wind lasts. Take, then, fig. 5 as representing a basin containing different water layers in stable equilibrium, for the sake of convenience, we may presume that only three water layers of different specific gravity are represented. The layers themselves will then all be devoid of isosteric surfaces, but in the dividing surfaces between the layers, a large number of isosteres will be found. When not subjected to the action of external forces, the three different kinds of water will

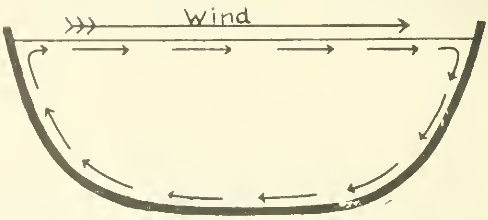


Fig. 4.—Wind currents in homogeneous water.

arrange themselves in horizontal strata, the specific gravity increasing with the depth. Should, now, a wind arise, it will act upon the surface of the uppermost and lightest layer, the water of which this is composed being forced along in the direction of the wind. This layer will then become wedge-shaped, as shown in fig. 6, its water at the same time circulating in the manner indicated in fig. 4. Owing to the friction thus caused, a certain amount of the movement in this surface layer will be communicated to the layer immediately beneath, which in its turn begins to circulate, but in the opposite direction, the combined movement exactly corresponding to that of two cog-wheels working together. Finally, the bottom layer will be similarly set in motion by the one above it, and will commence to circulate in the same direction as the surface layer, albeit at a slower rate.

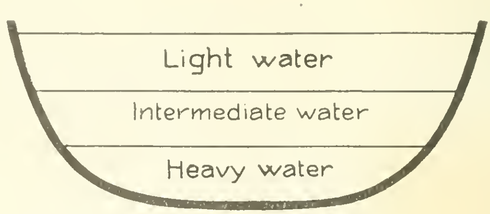


Fig. 5.—Water layers in stable juxtaposition.

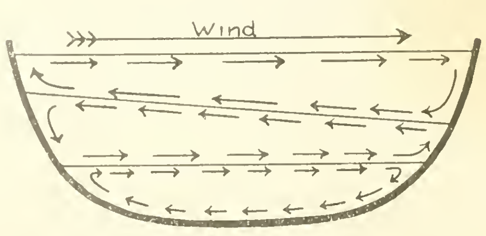


Fig. 6.—Wind currents in stable water layers.

The above simple example will serve to give an idea as to the complicated movement caused by the wind in water layers of stable relative position. The system of strata and movement of the water shown in figs. 5 and 6 are of very frequent occurrence in the sea; in some places, however, the density increases more continuously with the depth, and isosteric surfaces are then found in all parts of the water. Such waters may be regarded as consisting of an infinite number of infinitely thin strata. The movement of the water here is highly restricted, which gives rise to very peculiar dynamic phenomena. The water assumes a remarkable power of resistance against the action of external forces, and when these cease to operate, it returns to its original position.

Let us now endeavour to ascertain the cause of this. Taking any one of the isosteric sections in either of plates VIII and IX, we imagine a water sample from one of the isosteric surfaces transferred to a greater depth. It will here be lighter than its surroundings, and will therefore, according to the Archimedean principle, rise until it once more reaches the isosteric surface from which it was taken, and there it will remain. In the same way, if a sample of water be shifted to a point above that whence it was taken, it will be heavier than its surroundings, and will sink until it reaches the isosteric surface corresponding to its own specific gravity. It is otherwise, however, when a sample of water is moved along the isosteric surface. Here its specific gravity remains equal to that of its surroundings, and no force arises which would occasion its return to the original position. Thus we see that the water can only move along the isosteric surfaces, and not transversely through them. In other words, the scope of movement of the water, instead of being tri-dimensional, is restricted to the two dimensions.

The constant validity of this principle throughout the whole of our present area of investigation is most clearly shown by the existence, and extraordinary permanence, of the cold water layer. It is at once evident that no vertical convection can take place through this layer, the movement of the water being strictly confined to the horizontal.

It is therefore of particular importance to ascertain at what depths the water particles composing one and the same isosteric surface are to be found. For the sake of convenience we may here content ourselves with examining the isosteres $v_1 = 400$, 500, 600, etc. These depths may easily be found, by interpolation, from the v_1 column in table 1, and are here included in table 2. In this table, B indicates that the isosteric surface in question touches the bottom, and * that it cuts the surface of the sea before reaching the hydrographical station concerned. Plates X and XI show some of these figures for depth at their proper position within the area of investigation. Here also, lines are drawn to indicate the intersection of the isosteric surfaces with the surface of the sea. This figure shows at a glance why it is that the surface water, during the cold season, keeps to the coastal zone, but is able during the warmer months to move farther out. Another point immediately evident is the very high degree in which the heating of the surface water by the sun's rays contributes to its freedom of movement.

4. FORCES DERIVED FROM THE DISTRIBUTION OF DENSITY.

The Archimedean principle itself teaches us a great deal as to the forces in the sea which are derived from the distribution of density. When the water at a certain point is specifically lighter than its surroundings, it tends to rise, while if heavier, it will tend to sink. Let A, in the section fig. 7, represent light, and B, heavy water, the two strata being separated by an oblique surface. The deeper portion of the light layer A is then surrounded by heavier water, and is specifically lighter than its surroundings, according to the Archimedean principle, therefore, it will be driven

upwards, as indicated by the arrow in the figure. The highest portion of the layer *B* is heavier than its surroundings, and has thus a tendency to downward movement here similarly indicated. Thus we see, that according to the Archimedean principle, the lower portion of the dividing surface will be raised, and the upper lowered: in other words, the dividing surface will become horizontal.

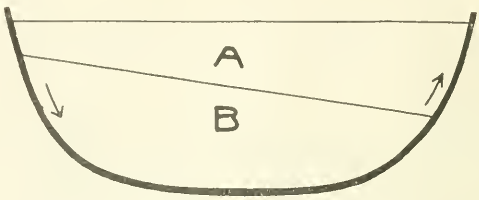


Fig. 7.—Archimedean forces in stable strata.

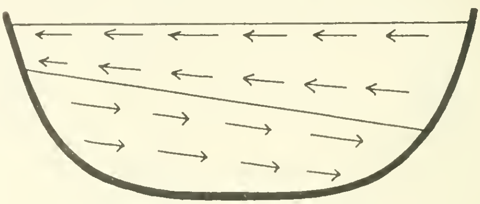


Fig. 8.—Movement occasioned by the forces shown in Fig. 7.

It is easy to understand what movements will be thus occasioned in the water itself. The water will be forced from the thicker to the thinner portion of the stratum, until finally a layer of uniform thickness is produced. We have thus horizontal movements, proceeding in a direction from the thicker towards the thinner portions of the layers, so that the forces indicated in fig. 7 occasion the movements shown in fig. 8.

This simple argument is, as we shall subsequently see, of fundamental importance for the comprehension of the actual conditions in the sea, and will also help us to explain an interesting effect of the wind. The surface water in fig. 6 has been transformed into a wedge-shaped stratum by the action of the wind. When the wind drops, this layer will, according to the Archimedean principle, tend to resume its normal uniform thickness, the water being forced from the thicker towards the thinner portion of the layer; i.e., in a direction contrary to that of the wind previously acting upon it. Thus the action of wind upon normally stable layers of water occasions, upon its cessation, a movement in the surface layer contrary to the former direction of the wind.

It may also happen that water is continually introduced into some portion of a stratum. The thickness of the stratum will then be greater at this point than in the surrounding portions, giving rise to Archimedean forces which drive the water from the point of inflow horizontally towards the farther limits of the stratum. In the tropics, great masses of water are heated by the rays of the sun. Such water becomes specifically lighter, and passes over into the surface layer, which in the tropics amounts to 600 metres depth, whereas at Spitzbergen it is only 200 metres. Thus the Archimedean forces drive the water from the tropics towards Spitzbergen. And the resulting current is that known as the Gulf Stream.

From the foregoing, also, it will be understood that the Gaspé current, the water of which is formed in the mouth of the St. Lawrence river, becomes continually shallower as it proceeds. To the west of the Gaspé peninsula it must be deeper than

to the east of there, and still shallower in the Cabot strait. It is this variation in depths which gives the current its forward movement.

The difference of level in the separating surfaces in the sea is of the same importance to the movement of sea-water as the varying level of the surface of a river to the movement of the latter. The force impelling a sea current may be calculated from the slope of the separating surface in the same manner in which the force of a river's current is calculated from the slope of its surface water. In the case of marine currents, however, we have to take into consideration the *difference* in density $\rho_1 - \rho_2$ between the two layers, instead of reckoning merely with the full density of the sea-water. The same thing should, as a matter of fact, be done in the case of a river; the density of the air above the water, however, is so slight as to be negligible in comparison with that of the river water. Save for this, the methods of calculation would be exactly identical for both river and sea currents.

We can also, if preferred, reduce the difference in level of the separating surfaces correspondingly, multiplying them by

$$\frac{\rho_1 - \rho_2}{\rho}$$

and then reckon with the entire mass of the sea current.

This reduction of density naturally tends to diminish considerably the effect of a marine current; this is, however, great enough, owing to the enormous mass of water involved in the movement. Thus for instance, the difference in level of the separating surface in the course of the Gulf stream, amounting to 400 m., is reduced to only 1·5 m. But as the Gulf stream carries 25,000,000 tons of sea-water per second, this slight waterfall yet supplies a force equivalent to 500,000,000 horse-power, which is sufficient to overcome the friction and keep the current in motion.

From measurements of the depth and velocity of the Gaspé and Cabot currents we may calculate, in a similar way, the force and amount of energy which serves to maintain the movement of this current, so important for the hydrographical conditions in the Gulf of St. Lawrence.

Obviously, this simple quantitative method is enormously valuable in determining the causes, features and effects of a marine current.

The propulsion of the currents is thus the most important work performed by the Archimedean forces in the sea. They have, however, also another function of importance here. When an external force acts in the water, the latter is at first moved in the direction whither that force is tending, *vide* fig. 6. This gives rise to Archimedean forces tending in the opposite direction. As long as this displacement of the water continues the strength of the opposing Archimedean forces continually increases. When this has reached a power equal to that of the external force in operation, a state of equilibrium is attained, and the movement of the water ceases. From the Archimedean forces, therefore, we can ascertain in this case at once the direction and magnitude of the external force.

We can thus, from the form of the isosteric surfaces, discover what forces are acting upon the water. Plates X and XI, showing the shape of the isosteric surfaces in the Canadian Atlantic waters during the spring and summer of 1915, thus give us at the same time an idea of the forces then acting upon the water there. We see that the isosteric surfaces slope from out to sea inwards towards Cabot strait, reaching there a considerable depth. This shows, that some force is at work, tending in towards the gulf of St. Lawrence. It is the deflecting force of the earth's rotation, which presses the Labrador current to the right, in towards Cabot strait, and causes the isosteric surfaces to slope as we have seen. This obliquity, however, again gives rise to Archimedean forces in the water, pressing outwards, and opposing the inflow of the Labrador current into the gulf. And from the magnitude of the Archimedean forces here we can, as will later be seen, ascertain the velocity of the Labrador current in this

region. Doubtless, also, similar forces of resistance oppose the inflow of the Labrador current into Belle Isle strait.

Within the gulf of St. Lawrence, it is noticeable that the isosteric surfaces as a rule lie deeper in the peripheral portions than in the central part. This suggests the action of a force tending radially outward from the centre; evidently the centrifugal force occasioned by the cyclonic circulation of the water in the gulf.

Many other interesting details may be seen from Plates X and XI. In section IV, for instance, the 700 isosteric surface lies deeper in the middle of the sound than off the Gaspé coast, evidently a quite abnormal situation, due to some strong external force, which, at the time when the section was taken, must have been operating in a direction from the Gaspé coast to Anticosti, probably a strong south west wind.

5. STABILITY OF THE WATER IN THE NEWFOUNDLAND AREA.

The stability of sea-water may conveniently be characterized by noting the number of isosteric surfaces per 10 metres of depth. The third column in table 1 shows this value for all depth intervals in the present investigations.

It is of great importance to find a method of graphic illustration for this feature, indicating the condition of the water. After various attempts, I have selected the following as being most convenient. The state of a vertical in the sea is represented by a vertical line, the thickness of which is drawn proportionate to the stability. Plates XII and XIII illustrate, in this manner, the stability of the sea-water at the hydrographical stations with which we are here concerned.

By this method, homogeneous water is indicated by an infinitely narrow vertical, see fig. 9 a, and water of constant stability, i.e. the specific volume of which decreases in linear proportion to the depth, by a line of equal thickness throughout, (fig. 9 b). In the sea, owing to rainfall and the inflow of fresh water, as also to the heating of the surface water by the sun, the decrease of specific volume with increasing depth is far more marked in the upper water layers than at greater depths. This is correspondingly shown in fig. 9 c. During a heavy gale the surface water is so stirred as to produce a homogeneous surface layer, the transition here answering to that apparent in passing from fig. 9 c to fig. 9 d. In the spring, the melting of the ice occasions a downflow of ice-cold water from the surface to an intermediate depth. A homogeneous layer is thus produced, here indicated by the narrowed portions in the diagram, fig. 9e.

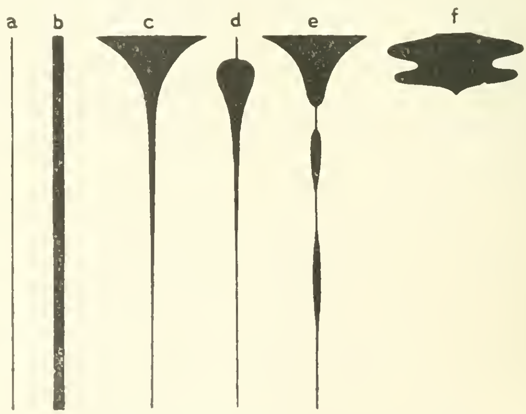


Fig. 9.—Diagram of the stability of the sea water.

In the coastal zones, there is often a current of specifically lighter water. Owing to the inflow from rivers and streams, the surface water becomes especially stable.

Another maximum of stability occurs at somewhat greater depth where the transition from the light coastal current to the heavier subjacent layer occurs. This is shown in fig. 9 f.

All these features, together with others, are illustrated in plates XII and XIII. The diagrams for stability are, as will have been seen from the foregoing, extremely instructive when discussing the condition of the sea and the causes which produce the various hydrographical situations there occurring.

6.—INFLUENCE OF THE WIND UPON THE MOVEMENT OF SEA-WATER.

In chapter 3, the various effects of the wind upon homogeneous water and upon water in layers, has already been shown, *vide* figs. 4 and 6. Still more remarkable is the action of the wind upon water in which the specific gravity increases continuously with the depth. Let fig. 10 be a vertical section through a sea basin containing such water, the horizontal lines 1-7 representing the isosterics. We presume that, for the time being, no other forces are at work here beyond that of gravitation, and that the water is at rest; the isosteric surfaces will thus lie perfectly horizontal. In fig. 10, the isosteres are closest at the surface of the sea, where the stability of the water will in consequence be the greatest. Fig. 9 e gives the diagram of stability for fig. 10. If now a wind commence to blow, a displacement of the upper water will occur, this following the direction of the wind; as, however, the water particles belonging to an isosteric surface cannot leave the same, and as no water can penetrate through these surfaces, the effect of the wind in this case will be confined to the deformation shown in fig. 11.

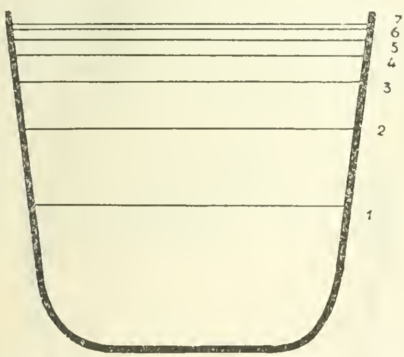


Fig. 10.—Stable sea water in equilibrium.

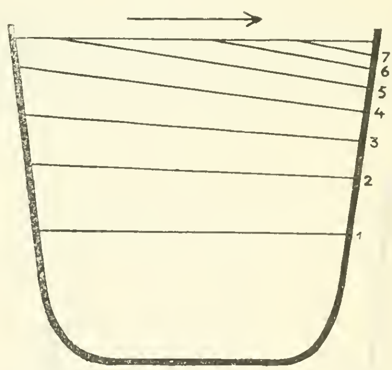


Fig. 11.—Influence of the wind on stable sea water.

The isosteric surfaces retain their individuality, and the volume of water between them remains unchanged despite the wind. The displacement of the water in the direction of the wind causes the isosteric surfaces to slope more and more, giving rise to a strong system of Archimedean forces, which tend to drive the surface water back against the wind. These opposing forces continue to increase, until at last the water no longer flows in the direction of the wind; a state of equilibrium is reached, and from the magnitude of the Archimedean forces required to bring about the same, we may subsequently calculate the force originally brought to bear by the wind itself. When the wind grows fainter, or ceases altogether, the Archimedean forces drive the water back in a direction opposite to that previously followed by the wind. As a rule, the water now flows back too far, so that the isosteric surfaces slope the reverse way. This gives rise to new Archimedean forces which send the water back once more in the original direction of the wind. In this way the backward and forward movement may be

repeated several times, until equilibrium is attained. When this occurs, the isosteres will be in precisely their old position, and the state of the water exactly what it was before the commencement of the wind.

The sea-water thus reacts more after the manner of an elastic body than a fluid, when subjected to the influence of forces acting upon it. The forces in question can only occasion a certain degree of deformation, and as soon as they cease to operate, the water returns to its former condition. External forces produce, so to speak, effects as upon a mass of jelly.

The Archimedean forces thus play very much the same part in sea-water as that of elasticity in a solid. It may occasionally happen that the external forces acting upon the sea water reach a magnitude exceeding the highest possible value which can be attained by the Archimedean forces. A catastrophe then takes place, and an entirely new state of things is brought about, exactly as when the limit of elasticity in a solid is exceeded.

The maximal value of the Archimedean forces is reached when the isosteres become vertical. Should external forces exceeding this maximal value be brought into play, then the water layers will jibe over, as shown in fig. 12, which illustrates the distribution of density under a very strong wind. Now, however, light water is brought down beneath heavier; the stability is upset, and a strong vertical convection ensues, whereby the whole of the water affected is mixed up into one single homogeneous layer. The specific volume of this layer will, of course, be equal to the mean specific volume of the strata of which it was composed, and between this and the water beneath there will be a sharply defined difference of density. In the homogeneous layer, there are no isosteres, and consequently, no Archimedean forces will be formed, so that the water therein contained will follow without resistance the direction of external forces acting upon it. The circulation here will therefore be highly intensive, as shown in fig. 13, so that the water will continue homogeneous, and exert a continual friction upon the layer beneath, thus maintaining the sharply defined limit of density between the two. This friction occasions a gradual absorption of the water from the lower layer, so that the upper one will tend to increase in volume and specific gravity.

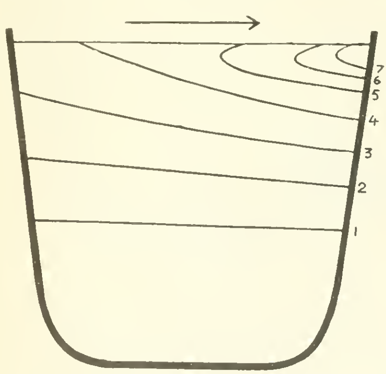


Fig. 12.—Water layers jibing in a high wind.

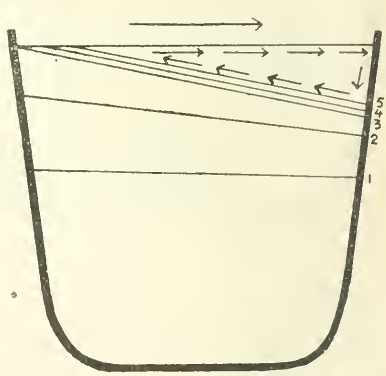


Fig. 13.—Strong circulation in surface layer after jibing.

When the external forces which brought about the transformation have subsided, and the isosteres have resumed their horizontal position, the distribution of density will naturally not be the same as before the forces in question had commenced to operate, *vide* fig. 10. Instead of this, we now find a homogeneous surface layer of great volume, and between this and the water beneath, a sharply marked break in the density, *vide* fig. 14. This is the reason why the greatest variation of density with

depth in the sea is often found, not at the surface, but at some distance beneath, *vide,* fig, 9 d, and plates XII and XIII.

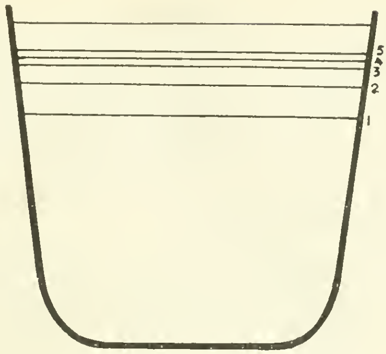


Fig. 14.—State of sea water after a storm.

Obviously the greater the stability of the water, the more difficult will it be to make the surface water jibe over in this manner; whence again it follows, that the phenomenon is more easily occasioned in winter than in summer. In other words, the surface water exhibits a far greater power of resistance to the wind in summer than in winter. This peculiarity has been remarked by fishermen on the west coast of Sweden, who declare that the sea-water is harder or heavier in summer than at other times of the year.

With water in layers, the matter is naturally far simpler, *vide* fig. 6, than where the density increases continuously with the depth. Even in such stratified water, however, many dynamically and hydrographically interesting phenomena may occur. It is instructive to begin by producing such experimentally, and afterwards observe the corresponding realities in the sea; by this method, as by no other, it is possible to arrive at an intimate understanding of oceanographical phenomena.

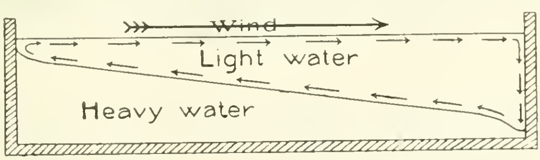


Fig. 15.—Experiment illustrating action of wind upon water in strata.

I purpose now to describe some experiments which I have carried out as illustrative of the influence of wind upon stratified water. A tank 100 cm. long, 25 cm. deep, and 3 cm. across, with glass walls, was filled to a height of 10 cm. with fresh water. By means of a thin tube, heavier salt water was then introduced beneath this, making another layer 10 cm. deep. With the aid of an electric arc lamp, a picture of the tank was then projected on to a white sheet, whereby the separating surface between the two water layers was rendered very distinctly visible, owing to the refraction of the light. As long as the water was left undisturbed, the boundary line was horizontal, and the layer of uniform thickness. By means of a blower, a strong current of air was then driven across the surface of the water, when the separating line took the direction shown in fig. 15. A point especially worthy of note is the depression at that end of the reservoir to which the wind was directed. This is

caused by the water in the upper layer having its current there directed vertically downwards, and striking against the separating surface. At the other end of the

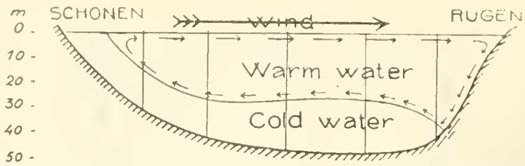


Fig. 16.—Wind and distribution of temperature, with probable movement of the water, in the southern part of the Baltic, 1 August 1907.

reservoir also, the separating surface is seen to be slightly rounded off where the current turns. That corresponding deformations of the surface layer occur in the sea will be seen from the hydrographical sections in figs. 16 and 17.

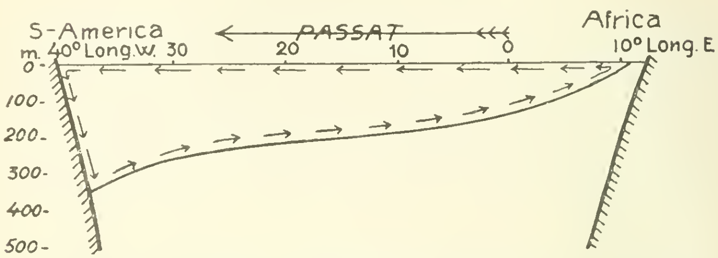


Fig. 17.—Wind, 15° isotherm, and probable movement of the water between Africa and S. America, lat. 20° S.

Owing to the circulation in the surface layer in fig. 15, the water therein remained very homogeneous. From the continual friction upon the layer beneath, the surface layer absorbed into itself some of the water adjacent, and thus gradually increased in volume. The longer the experiment lasted, the thicker and salter would the surface layer grow. The same thing would probably take place in the sea with a continual wind.

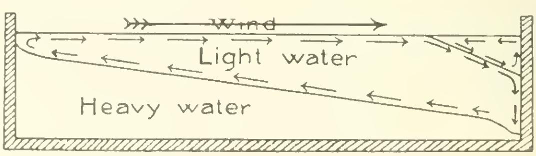


Fig. 18.—Experiment illustrating current opposed to the wind on the weather toward shore.

I now poured a small quantity of fresh water into the water already in the tank, as answering to rainfall, or inflow from rivers and streams into the sea. This fresh water was driven by the current of air towards the end of the tank against which the wind was blowing, forming a triangular inset there, as shown in fig. 18. It was here distinctly subjected to two forces, firstly the wind, endeavouring to bring about a circulation where the surface water moves in the direction of the wind, and secondly the current beneath, seeking to induce a circulation where the surface water moves against the direction of the wind. The latter, however, obtained the mastery, as shown in

fig. 18. We see, then, that the peculiar phenomenon may arise of the wind occasioning a surface current in a direction opposite to its own, on the weather shore. This I have, as a matter of fact, frequently observed myself in the Gullmarfjord, on the west coast of Sweden. When the wind is blowing directly onshore, a situation exactly identical with that shown in fig. 18 may arise. Should it, however, be blowing obliquely towards land, then this will occasion a screwing movement in the triangular inset, also probably in that beneath, *vide* fig. 19, showing direction of the wind and movement of the water in Gullmarfjord, seen from above. The respective densities of the water layers in the gulf of St. Lawrence are so similar to those in the Gullmarfjord, that the same phenomenon should also be of frequent occurrence there.

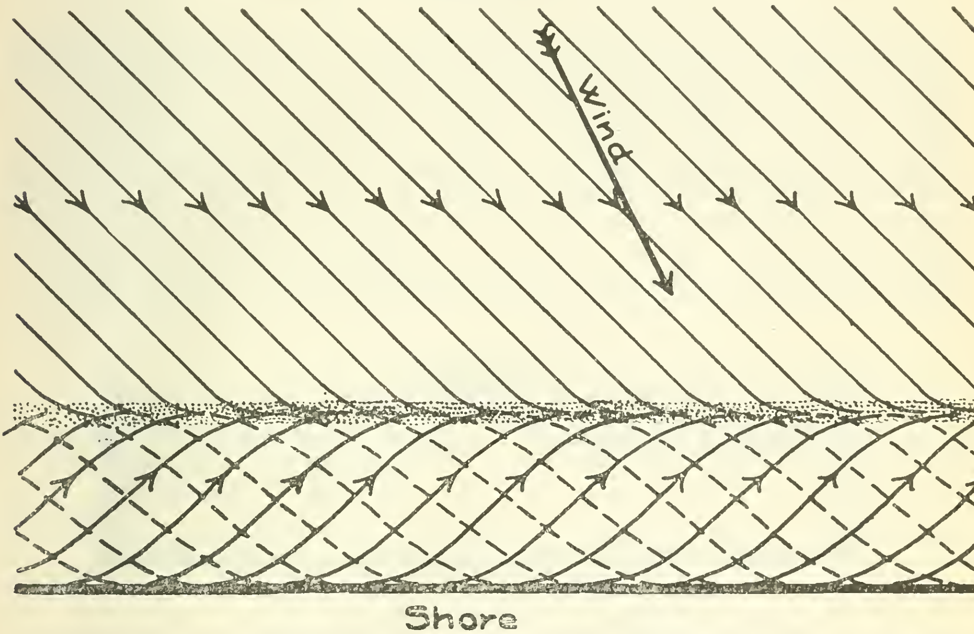


Fig. 19.—Wind and wind currents in the Gullmarfjord.

At the point where the two surface currents meet, all floating objects, such as driftwood, cork, froth, etc., will collect; this line is therefore easily distinguishable. Off the west coast of Sweden, there is, as a rule, a line of this sort generally to be seen running parallel with the shore. This is the boundary line between the Baltic current and the heavier water outside. When the fishing boats sail from Marstrand out to sea, they often follow one another in a straight line. On passing this boundary, however, their line is broken, and the boats outside do not move in the same direction as those within the margin, although steering the same course, and with their sails set just as before. This is evidently due to the fact that the movement of the water is not the same inside and outside the boundary line. A fisherman who had set his drift net out one night right across the line, had it cut clean across, and the pieces drawn into the mass of floating refuse. Next day he sailed northward along the line and found them there. This shows that high relative velocities are to be found in this drift line, which was only to be expected, after what we have seen in fig. 19.

The underlying strata are also affected, through friction, by the layers acted on directly by the wind. And it may then occur that even the cold deep water, when

drawn up to the surface on the shore where the wind is blowing seawards will develop a movement opposed to the direction of the wind, *vide* fig. 20.

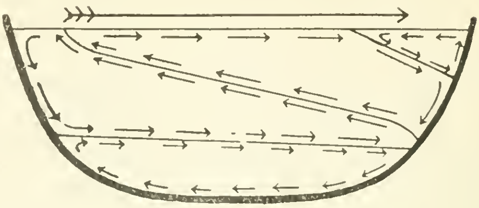


Fig. 20.—Current opposed to the wind on weather shore and lee.

In large areas, the wind cannot be regarded as a constant current of air progressing continuously over the whole area, but rather as a series of stormy gusts extending over a wide expanse. Such a storm, acting upon water in layers, produces a very large submarine wave, probably hundreds of metres high, which moves slowly forward in the direction of the wind, *vide* fig. 21. This wave is caused by the friction between the current of air and the surface layer. As the wave moves forward, the surface water in front of it must pass over behind the crest of the wave. A strong current, moving against the wind, thus arises in the surface layer, and this will make itself apparent even before the storm itself has reached the same point, thus serving as a storm warning. From fig. 21, it will be seen that the current flowing in a direction opposite to that of the wind continues to do so for some little time after the wind has come up,

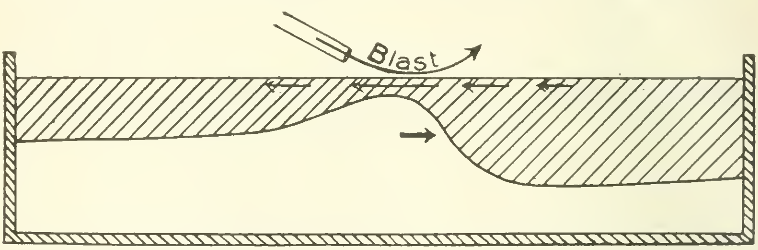


Fig. 21.—Surface current on the approach of a storm.

but then decreases in force. Such currents against the wind have frequently been observed in Canadian waters.

7.—INFLUENCE OF THE EARTH'S ROTATION ON THE MOVEMENTS OF THE WATER IN THE SEA.

Of all the forces acting upon the sea-water, that of the earth's rotation is the one which, as regards its effects, is most remarkable and difficult of comprehension. It is frequently found to force light water downwards, and heavier water to the surface, with the result that the distribution of density appears strange and mysterious. I am inclined to believe that our inability to comprehend the effects of this force is principally due to the fact that we have no senses for the direct perception of the rotation of the earth. All our direct perceptions indicate the earth as motionless. True, we have learned at school that the earth rotates, and can also more or less form an idea of its doing so, but as a matter of fact, in our daily life, as in the laboratory, we are independent of such rotation. All the small phenomena around us we are accustomed to view from the standpoint of an immobile earth. When, therefore, in discussing the movements of the sea, the rotation of the earth is seen to take a prominent place, its effects appear to us strange and inexplicable.

A being situated somewhere outside our planet, and observing, not only the phenomena taking place on the earth's surface, but also the rotation of the globe

itself, would be far better able to comprehend the actual movements of the sea than we are. From our point of view, the currents of the sea appear to evince an irrational tendency to veer to the right; an extra-terrestrial being would, however, see in this nothing but the natural effort of the water to continue its forward movement in a straight line, as its inertia demands. Let us then imagine ourselves to be such beings, viewing the earth from outside. We find, first of all, that the body of the planet moves about its axis in the space of twenty-four hours. At the poles, the surface of the earth also moves at this rate of rotation. At the equator, the influence of the earth's rotation is nil, as may be ascertained also by experiment with the Foucault pendulum. In the Canadian Atlantic region, the rotation of the earth's surface amounts, as circumstantially demonstrated in chapter 1, to about 11° per hour; i.e., the Canadian waters make a full turn in something like thirty-three hours; *vide* figs. 2 and 3. From fig. 3, also, we may see why it is that the water in more or less inclosed areas circulates cyclonically. All the currents in the area tend towards the right bank, and move along the same. This rule will always be found to apply in high latitudes. The Gulf stream, for instance, transporting water from the tropics to the Arctic ocean, keeps close to the coast of Europe, while the Polar current, which carries the light Arctic water southwards, hugs the shores of Canada. The result is a very marked cyclonic circulation in the North Atlantic ocean. In the North sea, the Skagerak, and in the Newfoundland area, the surface water everywhere exhibits a cyclonic circulation.

In the lower latitudes, on the other hand, the circulation of the surface water is anticyclonic, owing to the strong anticyclonic winds, and the slight effect of the earth's rotation there.

Let us now consider how this cyclonic and anticyclonic circulation would appear to an extra-terrestrial observer. The earth's rotation is cyclonic; every sea-basin thus also rotates cyclonically. When the water in any such basin circulates cyclonically in relation to the basin itself, this merely means that the rotation of the water is more rapid than that of the basin. And when the water circulates anticyclonically in its basin, this is in reality nothing but a cyclonic movement of the water at a velocity inferior to that of the basin itself.

It is obvious, however, that the centrifugal force of a rapidly rotating water layer will be greater than that of one rotating more slowly. When, therefore, the

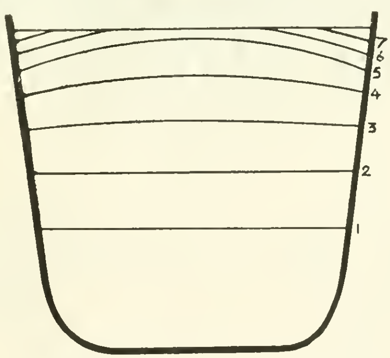


Fig. 22.—Distribution of density in a sea basin with cyclonic rotation of surface water.

surface water in a basin circulates cyclonically, this water will be flung radially outwards, so that the separating surface between this upper layer and the one immediately beneath will no longer be horizontal, but will develop a depression on the coasts, and a rise in the centre of the basin, *vide* fig. 22. The Archimedean forces thus called into play will be kept balanced by the difference between the centrifugal forces of the two layers.

From the Archimedean forces, therefore, we can calculate the centrifugal forces, and thus arrive at the transposition of the water. This ingenious method of calculating the movements of sea water will be employed in the following, when dealing with the Newfoundland area.

A contrasted distribution of density arises when the surface water circulates anticyclonically, as is the case in the horse latitudes. Here, the deep water rotates, as a matter of fact, with the Atlantic basin; the surface water, however, moving at a slower rate. The centrifugal force of the deep water is therefore greater than that of the surface water, and the former is consequently flung out more strongly than the latter. The result of this, again, is that the surface water keeps to the centre of the area (*vide* fig. 24 B), and this warm upper layer therefore reaches down at this point to a depth of 600 metres, whereas at the equator, its depth is only 200 metres.

Now, as we know, the diagram of velocity for a vertical line through a sea current assumes, owing to friction, the form of a parabola, the velocity being at its maximum a little below the surface of the sea. In the lower portions of the current it decreases greatly with increasing depth. When, therefore, the surface water in a basin circulates cyclonically, as before described, the cyclonic circulation and the

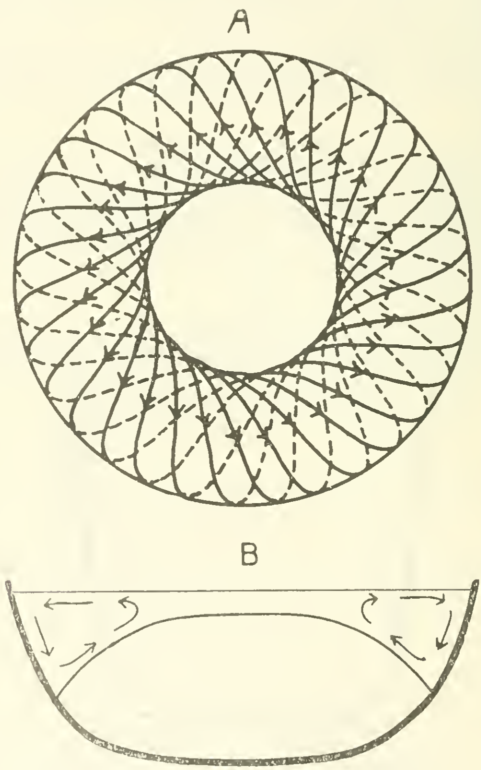


Fig. 23.—Screwing movement of surface water in cyclonic circulation.

centrifugal force will reach their maximum near the surface of the sea, decreasing rapidly with increasing depth. And the actual surface water will be flung out more strongly than the water in the lower portions of the surface layer. The effect of this is that the former moves toward land, and the latter out to sea (*vide* fig 23 B).

And in its forward progress, the current thus makes a kind of screw movement, exactly corresponding to the screwing forwards of an ordinary screw, fig. 23 A.

In the Sargasso sea, the anticyclonic circulation is at its maximum in the surface of the sea, the centrifugal force being there at a minimum. The lower portions of the surface layer are flung outwards with greater force than the surface water itself. This gives rise to a screwing movement of the water, the surface water tending towards the centre of the Sargasso sea, and the deep water moving outwards from that centre, as shown in fig. 24. This explains the collection of floating matter in the Sargasso sea.

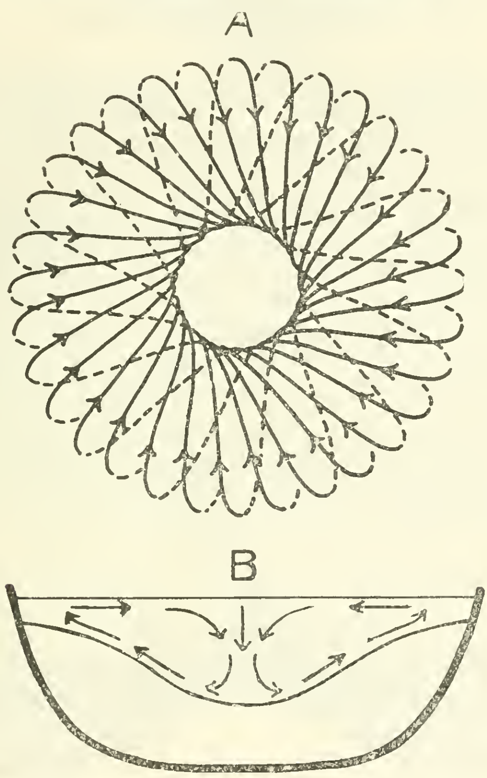


Fig. 24.—Movement of the water in the Sasgasso sea.

This tendency to screw forward is found in all sea currents in high latitudes, as a result of the earth's rotation. But the water of the northern hemisphere moves after the manner of an ordinary right-turned screw; that of the southern, however, screwing towards the left. The screwing tendency increases as $\sin\varphi$ where φ is the geographical latitude. Thus, at the equator, it is nil, and has its maximum at the poles.

If the water of an intermediate layer is moving in a certain direction, relatively to the layers above and below it, then it will turn off to the right from that direction, until it reaches the right side of the basin, against which it is pressed (fig. 25). Such a current will have its maximum of velocity at the centre, where the water is forced most strongly to the right, returning in the upper and lower portions of the stratum. There will thus be two screwing movements in such an intermediate

layer. The divergence of the isosteric surfaces (*vide* fig. 25) is one of the surest indications of the existence of such a deep water current.

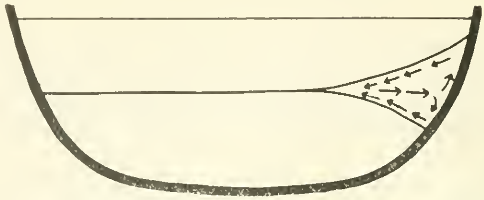


Fig. 25.—Screwing movement in a deep water current.

Finally, some experiments made with a rotating water tank remain to be described. This tank was 30 cm. long, 10 cm. broad, and 10 cm. high. A surface layer of fresh water, 4 cm. deep, was poured in, and a bottom layer of salt water, also 4 cm. deep, introduced beneath the first. Before the tank was set in motion, a vertical current of air was applied to the surface of the water; the result will be seen from fig. 26. Under the influence of this current of air, the surface layer diminished in thickness, the bottom layer increasing, evidently as a result of friction between the surface of the water and the air, which poured out radially to all sides. The tank was then caused to rotate about a vertical axis through its centre, when the situation shown in fig. 27 was observed; i.e., the exact opposite of that shown in fig. 26. The cause of this accumulation of the surface water under the air current is evidently this: the rotation of the surface water is somewhat retarded by the radially directed air, which renders its velocity less than that of the tank, whereas the bottom layer of water rotates at the same velocity as the tank itself. Consequently the centrifugal force would be greater in the bottom layer than in the surface water, and the bottom water would therefore be driven out to the ends of the tank, while the surface water massed in its centre.

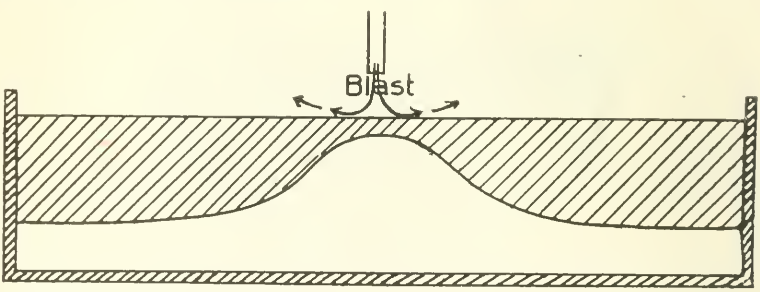


Fig. 26.—Experiment with vertical air blast against surface of water in layers. (Tank at rest.)

Lastly, by means of a series of obliquely placed tubes, a cyclonic circulation of air was applied to the surface of the water, the effect of this being to induce a rotation of the surface water at a higher velocity than that of the tank. This brought about the same distribution of the water mass as shown in fig. 26, evidently here owing to the fact that the centrifugal force was in this case greater in the surface layer than in the bottom water.

In the sea, therefore, an anticyclone should occasion an accumulation of the surface water beneath its centre, a good example of which is afforded by the Sargasso sea. A cyclone, on the other hand, would drive the surface water outwards to all sides, and draw up the bottom water beneath its centre.

The vertical movements of the water described in this chapter, which are due to the earth's rotation, are naturally opposed, in a very important degree, by the Archimedean forces. With water of very high stability, these forces may entirely prevent the screwing movement of the water, all that takes place being then a current

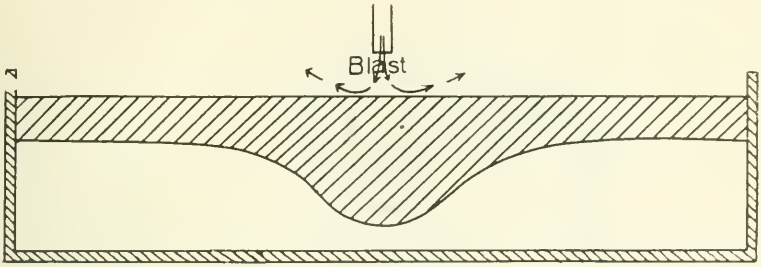


Fig. 27.—Experiment with vertical air blast against surface of water in layers. (Tank rotating.)

in the isosteric surfaces, which are deformed in the manner shown in fig. 22. In a coastal current, where the water is in layers of great stability, the surface water will therefore flow parallel with the coast. If, however, the stability of the strata be so slight that the deflecting tendency of the earth's rotation exceeds the maximal value of the Archimedean forces, then the screwing movement will thoroughly stir the water in which it takes place, rendering the layer highly homogeneous, so that the dividing surface between it and the next will be sharply defined. After this, there will be nothing to hinder the screwing movement of the water in this homogeneous layer, and the movement in question will thus attain its full development. This explains the high component of movement towards the coast in the surface portion of the comparatively homogeneous water south of Newfoundland, whereas in the Gaspe current, a layer formation of great stability, no such landward movement takes place (*vide* fig. 28). Even down on the banks to the south of Newfoundland, the water often flows northward, the bottom water, owing to the screwing movement, naturally having a component southwards. Thus the dangerous character of the Canadian Atlantic coast as regards navigation is due to the homogeneous nature of the water. If at any season the sea-water there should be overlaid by lighter surface water in stable layer formation, there would then be no danger of ships being driven on shore by the current, as long as such surface water was present.

In a similar manner, we should be able, from the movement of the water, to ascertain the stability of the same. If the water flows parallel with the coast, it is stable; whereas water setting in towards the shore will be homogeneous. On the eastern side of Newfoundland, for instance, the water flows up into the bays (*vide*

Fig. 28.—Movement of the water according to chart from Belle Isle to Boston, compiled from Sailing Directions, Survey of Tides and Currents in Canadian waters, and other sources.

fig. 28). From this we may conclude that the water here is of but slight stability. On the southeast coast of Newfoundland, on the other hand, the water sets outwards from the shore, even occasioning a reverse current in towards land. Here, therefore, the water is in stable layer formation.

8. INFLUENCE OF MELTING ICE UPON THE MOVEMENTS OF SEA-WATER.

One of the strongest and most effective causes of ocean currents and hydrographical changes is, as Prof. Otto Pettersson[1] has shown, the melting of ice. If a piece of ice be placed in a tank of sea-water, the water will soon exhibit very strong and distinct current movements, the melting of the ice also occasioning marked alterations in the temperature, salinity, and specific gravity of the water.

Professor Pettersson found by his experiments that the melting of the ice gave rise to three currents in the water, a cold surface current of low salinity proceeding in a direction away from the ice; below this a warm salt current moving toward the ice; and finally a cold salt bottom current away from the ice again.

I have also carried out some experiments of this nature with melting ice in sea-water. A glass-walled tank, 350 cm. long, 40 cm. broad, and 40 cm. deep, was filled with sea-water to a height of 35 cm. In one end of the tank was then placed a rectangular piece of ice measuring 61 cm. length, by 40 cm. width, and 23 cm. thickness. At the other end of the tank a current of water was introduced at a temperature of 8° C. and with a salinity of 30 per cent, the inflow taking place at the rate of 12 cm. per second with a corresponding outflow from the surface so as to maintain a con-

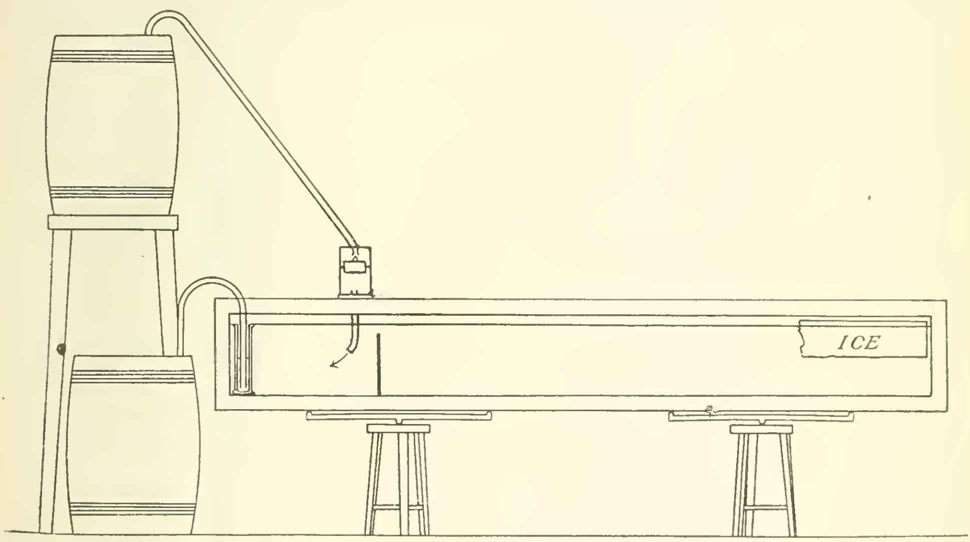


Fig. 29.—Ice melting experiment.

stant level. The outflow took place in a separate compartment of the tank, 75 cm. long, divided off from the remaining, consequently 275 cm. long by a partition 25 cm. high, so as to leave free communication between both portions of the tank through the space of 10 cm. above the partition, *vide* fig. 29. The object of this inflow arrangement was to procure stationary conditions in the tank. The system thus arrived at, by the way, is very much like the conditions prevalent in the gulf of St. Lawrence, which communicates with the ocean through Cabot strait.

The block of ice was placed in the tank at 11 a.m., and immediately commenced to melt at the rate of 0·80 cm.^{3} per second. As the surrounding water was brought into circulation, the rate of melting increased, so that by 12 o'clock it was 1·24 cm.^{3} per

[1] *O. Pettersson.* On the influence of ice-melting upon oceanic conditions. Svenska hydrografisk-biologiska kommissionens skrifter II. Gothenburg, 1905.

second, and by 1 o'clock 1·26 cm.^{3} per second. After this it decreased, chiefly owing to the fact that the surface of the ice block had diminished in size, but also on account of the lower temperature of the water in the tank. At 2 o'clock the rate of melting was 0·97 cm.^{3} per second, at 3 o'clock 0·70, at 4 p.m. 0·60, at 5 p.m. 0·53, at 6 p.m. 0·50, at 7 p.m. 0·50, and at 8 o'clock 0·50 cm.^{3} per second. Fig 30 shows the changes which took place in the shape of the ice during the process of melting. The depression *A* on the front of the block was caused by the warm water pressing against the ice at this point, and giving off its heat there, whereafter the water now cooled sinks down past *B*, where the ice melts at a slower rate, owing to the lower temperature of the water coming in contact with it there.

In order to measure the movement of the water in the tank, a solution of fuchsin in alcohol was prepared, in such proportion as to get a specific gravity as nearly as possible equal to that of the water. A portion of this solution was discharged into the water through a capillary glass tube at a point some 20 cm. in front of the depression *A* in the ice (fig. 30). The solution was carried at an even rate of speed into the depression, then sinking downwards, following the outline of the ice. At *B*, the rate of movement was diminished, and a small cloud of fuchsin was formed off the projecting point there. After this, the fuchsin particles were gradually driven in under the ice. The lower portions of the block was passed by at a great rate of speed, until the fuchsin reached the point *C*, where it slowly sank, and was caught by the bottom current which carries the water away from the ice.

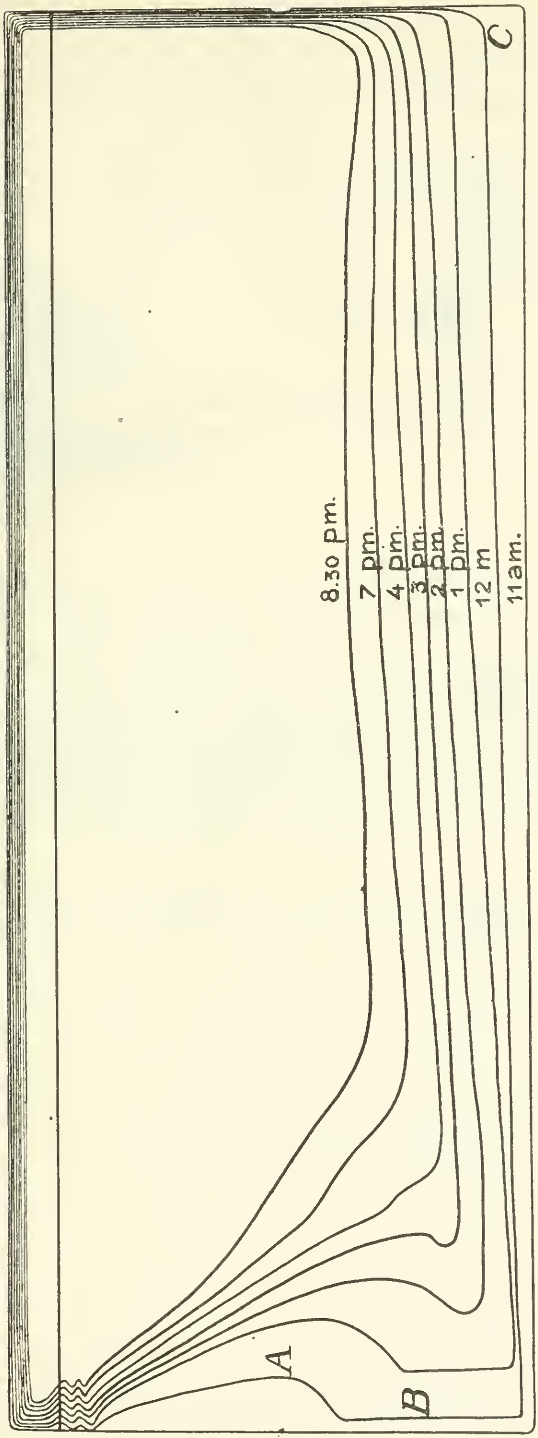


Fig. 30.—The melting of the ice.

A picture of the ice block being projected on to a white sheet by means of an arc lamp, it was seen that streaks were moving upward on the cloth, indicating that some of the melting water from the surface of the ice rises to the surface of the water, forming there a surface layer of fresher water; some portion of it, however, doubtless becoming mixed with the sea-water which is melting the ice and sinking

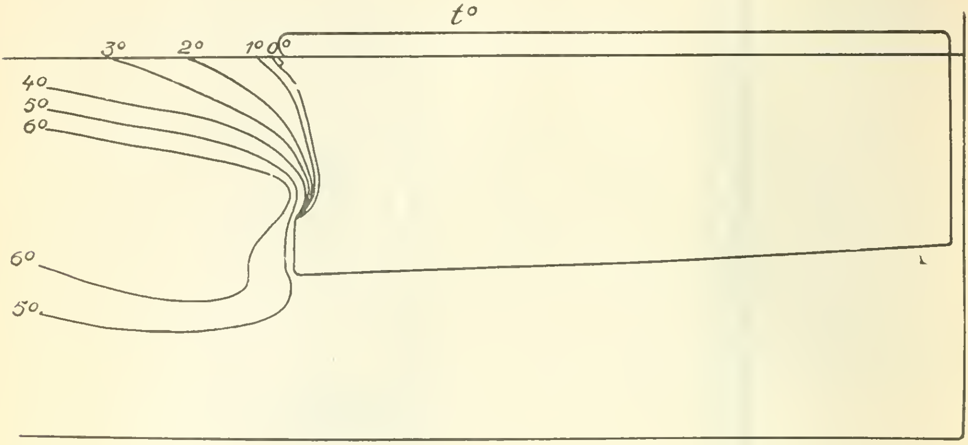


Fig. 31.—Distribution of salinity near the ice.

down with it. *Vide* figs. 31 and 32, showing distribution of salinity and temperature in front of the ice block.

In order to measure the movement of the water more exactly, a long capillary pipette was filled with potassium permanganate solution, and introduced vertically to the bottom of the tank from above. On being drawn up, it left behind it a fine vertical thread of the solution, which was afterwards visibly curved by the current. After the space of two minutes, a drawing was made of the thread as it then appeared. Fig.

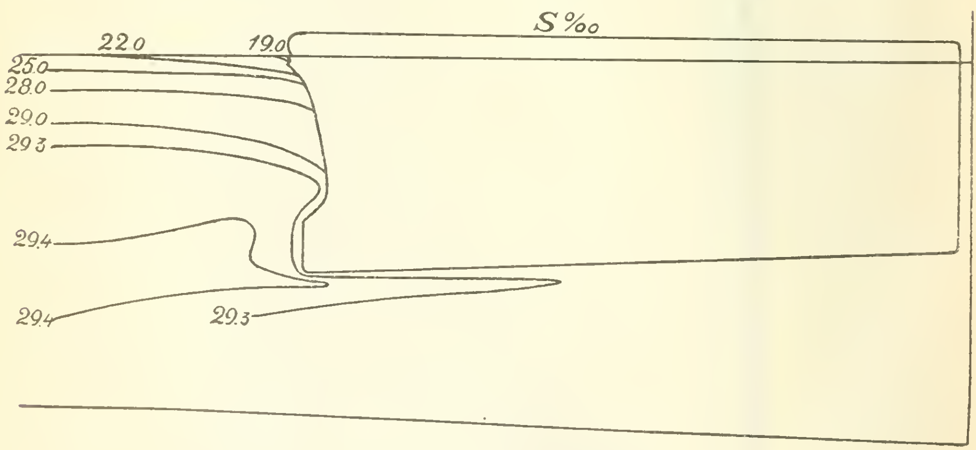


Fig. 32.—Distribution of the temperature near the ice.

33 shows the original vertical and subsequent altered course of the permanganate line. The horizontal lines thus indicates the movement of the water particles during the two minutes.

The velocity of the water was also measured in other parts of the tank. Fig. 34 shows the results of these measurements. It will be seen that the surface current is insignificant, that at the bottom, however, being quite considerable. The water actually moving towards the ice forms two currents, with a minimum of velocity between, the upper current being directed towards the front of the ice, and the lower against its underside, where the force of attraction appears to be very great. As a matter of fact,

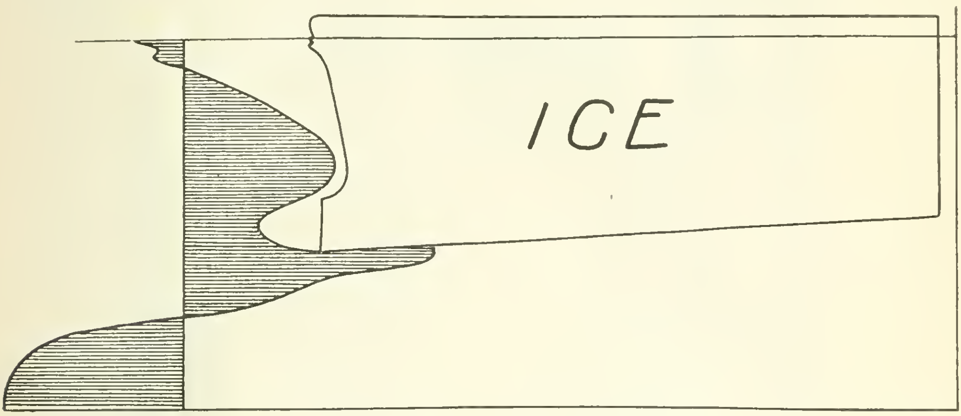


Fig. 33.—Movement of the water near the ice.

the ice melts equally much on its lower side as on its face, and the rear portion of the ice diminished, at any rate to begin with, more rapidly than the front part, *vide* fig. 30. The greatest velocity of the water and the greatest acceleration found in any part of the tank were localized about the lower side of the ice block. In the sea, where the vertical extent of the ice is insignificant as compared with its horizontal extension, this fact should probably be of the very highest importance.

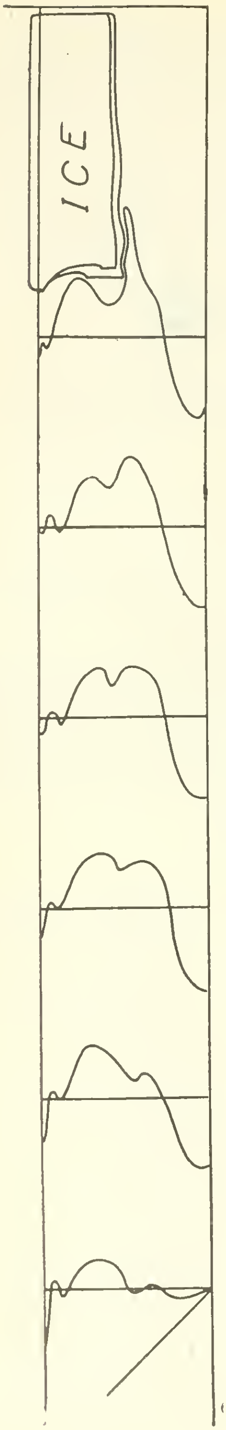


Fig. 34.—The movement of the water in the tank.

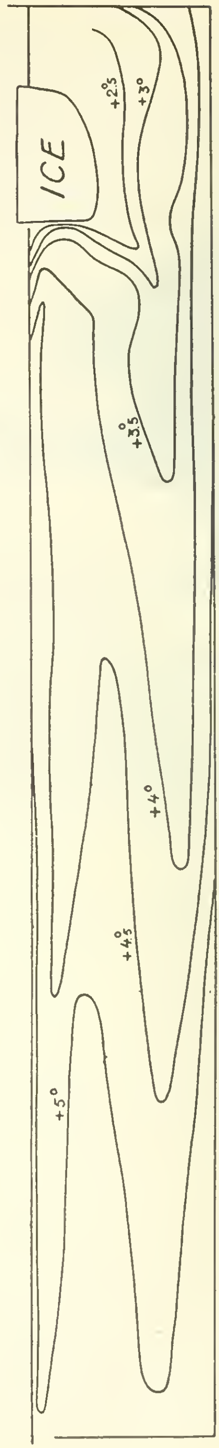


Fig. 35.—Distribution of the temperature by the melting of ice over a warm and very salt bottom layer.

In the experiment here described, it was not always possible to maintain a constant degree of salinity in the inflowing water. When the salinity increased, a warm saline layer with a slow inward movement was formed at the bottom of the tank. Above this was the cold outgoing current of lower salinity. And above this again warm water poured in towards the ice, with finally, at the surface, a thin layer of brackish water directed outwards, *vide* fig. 35. This situation corresponds very closely to the actual conditions in the gulf of St. Lawrence, where a cold intermediate layer is also found.

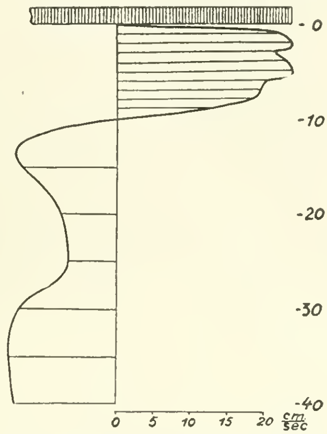


Fig. 36.—Movement of the water by the melting of the ice in the Gullmarfjord.

The experiment and observations mentioned above give a good insight into the origin and formation of the intermediate cold water layers in the Newfoundland area (*vide* tables IV and V). It has plainly been formed by the melting of the ice in the gulf of St. Lawrence and the Labrador current.

When the ice was melting in the Gullmarfjord I noticed it carefully, and measured the velocity of the water in a vertical line inside the ice edge, *vide* fig. 36, and also the temperature of the water in a section at right angles to the ice edge, *vide* fig. 37. From fig. 36 it will be seen that a strong current of water directed inward towards the ice existed down to 10 metres depth, and beneath this, a slighter outwards current right down to the bottom. Fig. 37 gives a very clear view of the manner in which the cooled water sinks in portions from the ice down into the depth below. The same thing doubtless takes place on the melting of the ice in the gulf of St. Lawrence, and in the Arctic ocean and other places.

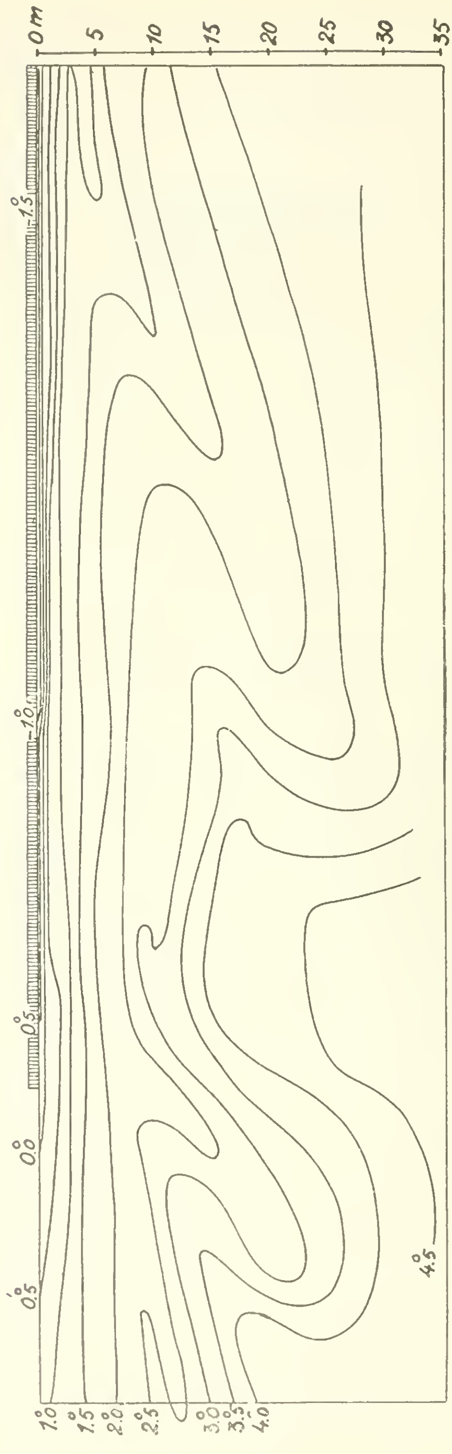


Fig. 37.—Distribution of the temperature by the melting of the ice in Gullmarfjord.

9. INFLUENCE OF FRICTION UPON THE MOVEMENT OF SEA-WATER.

Internal friction exerts a powerful regulating influence upon the movement of the water in an ocean current. In order to comprehend this, it will be necessary to consider the forces acting upon the water through friction. And it will simplify matters if we here disregard the insignificant vertical velocities in the water. Let us suppose that the water particle a has a velocity inferier both to that of the water above and of that below, *vide* fig. 38 a. The velocity of a will then be accelerated by friction with both these layers, until finally it attains their velocity. In this instance, then, the velocity of the water particle is accelerated by internal friction.

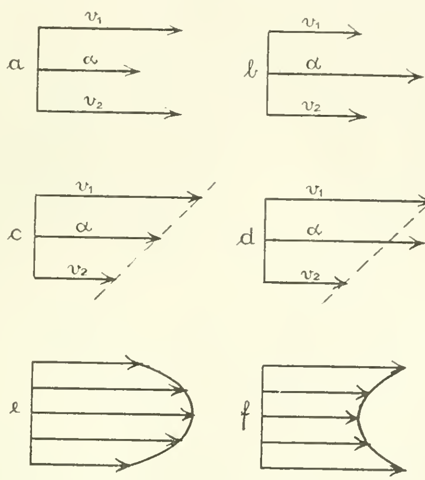


Fig. 38.—Frictional force as indicated by the movement of the water in a current

If, on the other hand, the water particle a is of greater velocity than the water above and below (fig. 38 b), it will be retarded until its velocity is equal to theirs. In this instance, the friction acts as a check upon the movement of a.

Again, if the velocity of a be equal to mean of the two values for velocity of the layer above and of that below, (fig. 38 c), then the retarding effect of the one will be equal to the accelerating influence of the other; i.e., the resultant value of the forces acting upon a through internal friction will be nil.

If the velocity of the particle a be not equal to the mean of the velocities above and below (fig. 38 d), then the friction in a will be the greater between it and the layer having the greater divergence in point of velocity from the particle a. The result of this will be that the velocity of a is finally brought, through friction, to a value equal to the mean of the two velocities in the water above and below it.

Where the current has a screwing movement, so that the vectors v_1 and v_2 (in fig. 38 d), do not lie in the same plane, or take opposite directions, then the vector representing a will constantly endeavour to attain a velocity and direction equal to the mean values for those of the vectors v_1 and v_2.

If we measure the velocity of the water at a great number of points in a vertical down through the sea, and draw up from these a co-ordinate system with the velocities as abscisses and depths as ordinates, then we obtain a diagram of velocity for the vertical in question. Where the resulting diagram is convex, as in fig. 38 e, then the velocity of each particle will be greater than the mean value of those immediately above and beneath; the current is then retarded by internal friction. If, on the other hand, the diagram presents a concave figure (fig. 38 f), then the velocity of each particle is less than the mean value of the velocities in the layers immediately above and below, wherefore the current will be accelerated by internal friction.

As a rule, the friction has a retarding effect upon the currents in the sea, so that the diagrams of velocity through these are generally convex. Let us suppose that all the water particles in one and the same current are retarded with the same force. The difference between the velocity of one water particle and the mean velocities above and below will then be constant for all water particles throughout the current. A diagram of velocity answering to these conditions is easily drawn, the figure being in this case a parabola (fig. 39).

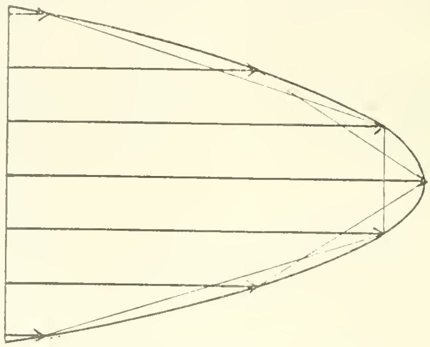


Fig. 39.—Diagram of velocity for a current with constant frictional resistance.

If the equation for this parabola be

$$u = az^2 \quad \text{(3a)}$$

then the force with which the friction retards each ccm. of the current will be

$$f = -2\,ak \quad \text{(3b)}$$

where k is the coefficient of friction. The more acute the parabola, the greater will be the check exerted upon the current by friction. In currents where the water flows at a great velocity in a thin layer, the retarding force is therefore very great, whereas in currents of great volume such as the Gulf Stream, it is insignificant.

In any current, where stationary conditions have been arrived at, the frictional resistance in the longitudinal direction of the current is nearly equal to, albeit naturally in an opposite direction to the force by which the current is impelled, and we can therefore, from the diagram of velocity, directly ascertain this force. If such a stationary current be disturbed by external influences, as for instance by that of the wind, the appearance of the diagram of velocity is at once changed, and we may, from the deformation occasioned therein, ascertain the magnitude and extent of the effect produced by the disturbing force upon the current. A diagram of velocity is therefore the best means we have of studying in detail the dynamic conditions of the ocean currents.

This analysis of the diagram of velocity is best carried out by dividing the curve into so small portions that each can be regarded as a parabolic curve with horizontal axis. For each such curve,, we then determine a and f, according to equations 3 a and 3 b.

Let us, for instance, consider the effect of the wind upon a surface current in the sea. The diagram of velocity for such a current normally takes the form of a parabola, the point of which lies immediately under the surface of the water, *vide* fig. 40 a, with a wind blowing across the sea in the same direction as the current, the diagram will assume the form shown in fig. 40 b, i.e. its upper portion will become concave, while the remaining parts will still continue convex. The upper portion of the current is thus accelerated by the friction. The effect of the wind extends down as far as the

deformation of the diagram takes place, and by calculating *a* and *f* for the different parts of the current, we can immediately ascertain the magnitude of the force acting upon each ccm. of the water by means of the wind. If, however, the wind be blowing against the current, then the diagram of velocity will be strongly curved back at the surface, *vide* fig. 40 c. Here the retarding force of the friction is very great, whereas at greater depths it retains its normal value. In this case likewise we may, by dividing up the diagram and finding *a* and *f* for each portion, ascertain the magnitude of the effect produced by the wind at different depths.

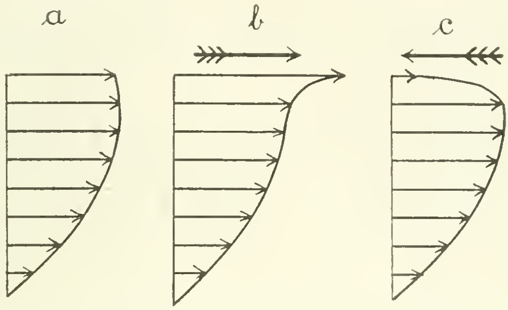


Fig. 40.—Diagram of velocity for a surface current in calm weather and with wind in same and the opposite direction.

In dealing thus with the diagram of velocity, due regard should be had to the imperfection of the methods of measurement. Thus the small irregularities in the upper part of the diagram fig. 36 cannot be considered as reflecting actual conditions, but are rather due, partly to the inaccuracy of the instruments employed, partly to the fact that the measurements were not taken at exactly the same time for the different depths. If these irregularities be levelled down, however, the parabolic form is quite distinct. We find then, that the water down to 10 metres depth is sucked in under the ice with great force, and that beneath this surface current, two outward currents of inferior velocity are found at 13 and 35 metres depth. The water between these last-named currents is drawn along by them.

The foregoing examples should suffice to give an idea as to the great value of the diagram of velocity in calculating the forces acting upon a current, in considering the disturbances to which it is subjected, and in studying its nature and composition generally. Such diagrams should therefore be more widely employed in marine investigations than has hitherto been the case.

10.—ON THE CAUSE AND THE EFFECTS OF OCEAN CURRENTS.

The causes which give rise to currents in the sea are either external forces, such as the action of the wind, or physical changes in the sea-water itself, occasioning an alteration of its specific gravity. We have thus two distinct categories of ocean currents, differing widely in character, and it is important to have a clear understanding of these.

If the surface water in a given area be subjected to physical change tending to increase its specific gravity, as for instance by cooling or evaporation, it will commence to sink, and the lighter surface water surrounding will flow in from all sides. And owing to the rotation of the earth, a cyclonic movement then sets in about the sinking centre. We have thus a movement in towards the centre, and at the same time a cyclonic movement round that centre, as shown in fig. 41 a. If, again, a cyclonic wind, by friction upon the surface of the sea, should set the surface water in cyclonic circulation, then the current in question will, owing to the earth's rotation, veer off

to the right, i.e. out from the centre. In this case, then, a cyclonic divergent movement is brought about, *vide* fig. 41 b.

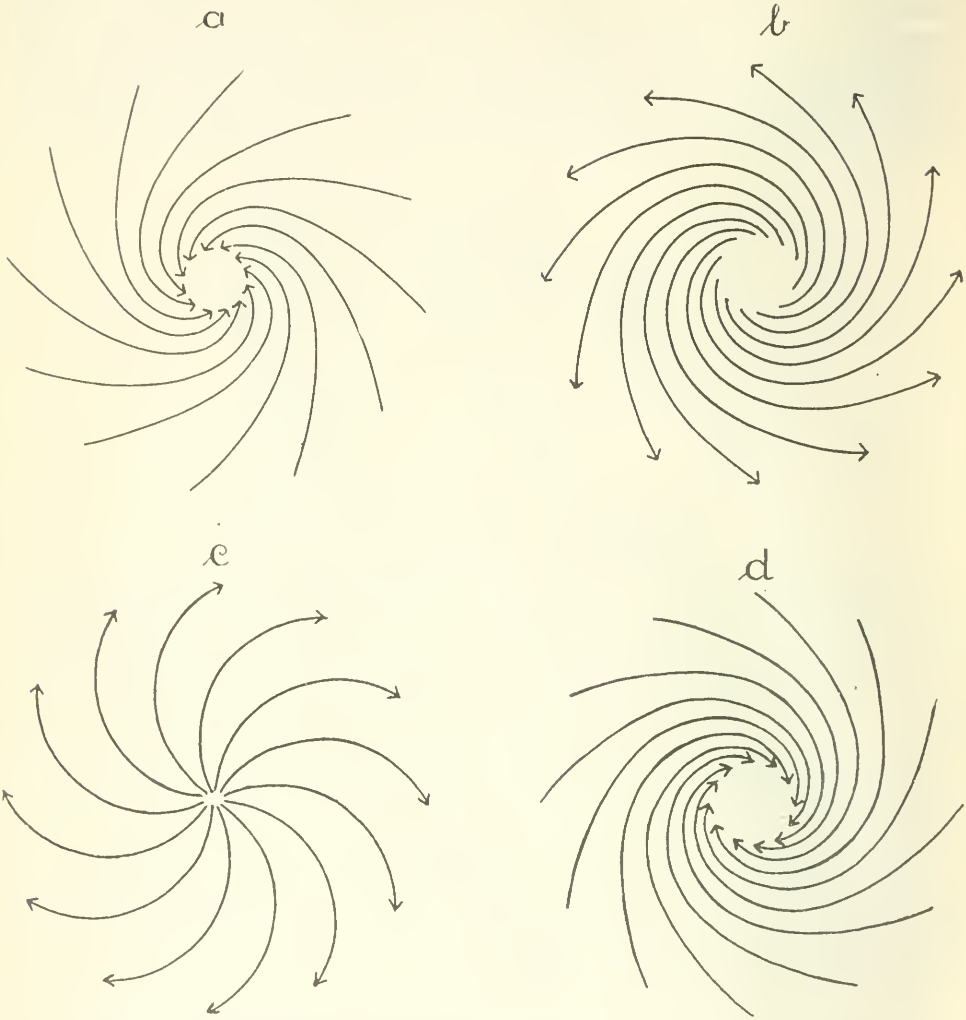


Fig. 41.—(*a*) Cyclonic current about a sinking centre.
(*b*) Cyclonic current produced by cyclonic wind.
(*c*) Anticyclonic current about a rising centre.
(*d*) Anticyclonic current produced by anticyclonic wind.

If, however, the specific gravity of sea water be diminished by physical change at any point, the water will rise towards the surface, spreading out there in all directions from the rising centre. And the earth's rotation occasioning at the same time an anticyclonic circulation, the total movement will then be divergently anticyclonic, fig. 41 c. If, on the other hand, an anticyclonic wind should set the surface water in anticyclonic circulation, then the current will be forced in by the earth's rotation towards the centre, giving rise to a convergent anticyclonic movement, fig. 41 d.

It is of course obvious, that a current concentrating upon a given centre will be far more strongly marked than one spreading its waters out in all directions. A current occasioned by cyclonic wind will therefore be but slightly perceptible, while those

induced by the action of anticyclonic winds, such as the current round the Sargasso Sea, and the analogous currents in the South Atlantic, the Indian ocean and the Pacific, will be far more markedly apparent. Moreover, the anticyclonic currents proceeding from a rising centre outward, will be comparatively insignificant, whereas the cyclonic movement of water in towards a sinking centre, e.g., towards the Arctic region, or the point where the Labrador current disappears, etc., will be strongly marked. We have, then, the following rule: Cyclonic currents in the sea are occasioned by physical causes, the anticyclonic currents by the action of the wind.

As the wind has no immediate effect upon the specific gravity of water, it follows that a current occasioned by the wind will be restricted to a single water layer, and is, in consequence, limited in extent, and simple in character. The Sargasso current, (*vide* fig. 24) may, as a matter of fact, be taken as the type of all great wind currents in the sea.

Despite their simplicity of character, however, these anticyclonic wind currents nevertheless present many features of interest, and are well worthy of further study. Such a vortex, with its powerful pressure in towards its centre, will be highly coherent and, in spite of the enormous extent involved, of distinctly individual character, with marked isolation from the surrounding water. One result of the pressure on the centre is that the vortex there attains a considerable depth. The Sargasso current, for instance, extends down to 600 metres. And, further, the strong vertical movement of the water in such a vortex enables it to carry down the heat of the surface water to a great depth; there is a continual wearing upon and heating of the subjacent colder water, so that the vortex is constantly intaking and assimilating water from below. The Sargasso current discharges unto the Gulf Stream 25,000,000 tons of water per second, which is as much as to say that it draws from its substratum just that quantity of water every second.

Currents arising from physical changes in the sea-water, on the other hand, are otherwise constituted, and behave in a very different way. They are not restricted to a single layer, but may traverse several such, and have thus far greater freedom of movement than the wind currents. Consequently, it is upon the former that the task of bringing about interchange between the waters of different regions and different depths devolves. The Gulf Stream is the type of this category.

The motive power in these currents is supplied by the Archimedean forces in the sea. When the specific gravity of the water in a certain layer has been sufficiently increased by physical change, it sinks down thence to a subjacent layer answering to its own specific gravity; where a decrease in the specific gravity takes place, the movement is of course reversed. In the Gulf Stream layer, water is introduced from the subjacent layer owing to rise of temperature taking place in the tropics; in the Arctic regions, on the other hand, water from the Gulf Stream passes, on cooling, from that current to the layer beneath.

Where water is thus introduced into a layer, the layer in question becomes thicker than its surroundings, and Archimedean forces then arise which drive the water of that layer from its place. Similarly, a layer losing some of its water becomes thinner, and the same forces tend to lead water thither from without. Owing to the earth's rotation, this movement of the water proceeds, not in a straight line, but in a spiral, as shown in figs. 41 a and c. If, in one and the same layer, water is introduced at one point and water carried off at another, then the layer in question will become thicker at the former than at the latter, giving rise to Archimedean forces which drive the water from the point of inflow to the point where water passes out. The Gulf Stream, for instance, is 600 metres deep in the tropics, but only 200 metres deep at Spitzbergen. We see, then, that the Archimedean forces in the Gulf Stream drive the water from the tropics towards Spitzbergen. Owing to the earth's rotation, the movement in question becomes S-shaped, *vide* fig. 42. If the water at the point

of inflow be set in motion by an anticyclonic wind, then the physical process by which the water is introduced is transferred to a greater depth, whereby the Archimedean

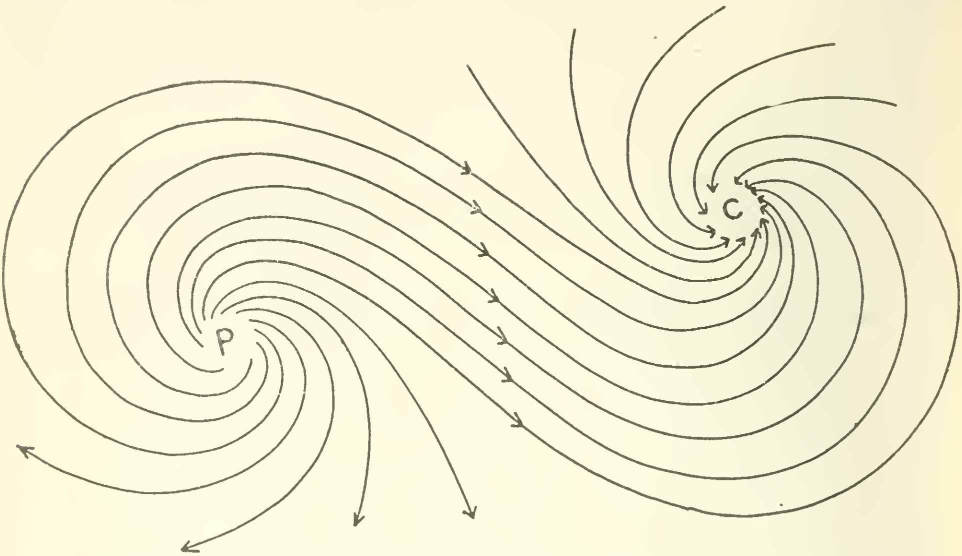


Fig. 42—Current from centre of production to centre of consumption in an oceanic layer.

forces attain a higher degree of intensity, and the current becomes greater. This takes place in the Gulf Stream, *vide* fig. 43.

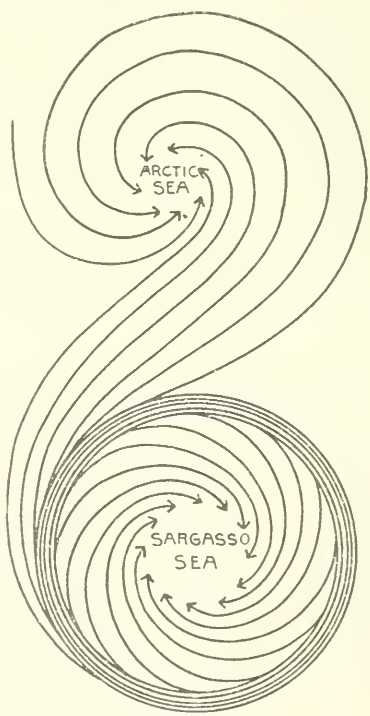


Fig. 43.—Schematic diagram showing movement of surface water in the Gulf Stream.

The effect of the currents originating in physical change in the water is then simply that of transporting water of a certain character from a region where such water abounds to regions where it is rare. And the quantity of water carried by such a current will depend entirely upon the production and consumption of the kind of water in question. The Gulf Stream carries about 25,000,000 tons of water per second. Hence, it follows that a corresponding amount of such water is produced in the tropics and consumed in the Arctic regions at the same rate.

And from this we may also conclude, that the complementary physical processes whereby water is added to or drawn from a certain layer adapt themselves so as to balance one another. What takes place is evidently this: a decrease of the quantity of water in a layer favours the development of forces tending to introduce water from without, and vice versa. And the present state of the water throughout the sea is the result of thousands of years of such adaptation.

The Archimedean forces which drive a current of this nature adapt themselves to the quantity of water to be carried forward and the degree of resistance to be encountered. In order to understand this, we may once more take the Gulf Stream as an example. If the production of Gulf Stream water in the tropics, and corresponding consumption of the same in the Arctic regions were to cease, then the lower boundary surface of the Gulf Stream would soon become horizontal, and the Archimedean forces which drive the current forward would disappear, with the result that the forward movement of the water itself would cease. If, on the other hand, the production and consumption of Gulf Stream water were to become greater than is at present the case, then the lower boundary surface of the Gulf Stream would assume a still steeper slope, and the Archimedean forces attain a higher degree of intensity than at present. This increase of force would arise in order to meet the necessity for transport of a greater volume of water than the Gulf Stream is now required to carry.

In order to demonstrate the importance of the Sargasso vortex to the Gulf Stream, the following experiment was made. A rectangular tank, 50 cm. long, 50 cm. deep, and 5 cm. broad, and having glass walls, was filled with water, and heating and cooling apparatus introduced, the latter constructed on the same principles as applied to the heating of rooms, etc., i.e., consisting of metal receptacles through which a current of warm or cold water could be transmitted. The pipes through which the heating or cooling water was carried to the receptacles were carefully isolated. In accordance with the conditions actually met with in the ocean, the cold centre was placed at the surface of the water at one end of the tank, and the warm one a little below the surface at the other end. The cold centre thus represents the cooling of the water in the Arctic regions, the heating apparatus answering to the corresponding influence at the bottom of the Sargasso vortex.

After the experiment had been in progress for some time, and stationary conditions arrived at, some potassium permanganate solution was introduced into the water near the middle of the tank, and immediately beneath the surface. The solution, easily visible on account of its colour, moved over to the cold centre, and then sank to the lower level of the warm centre, moved across to this, and then rose thence to the surface of the water, recommencing here its movement towards the cold centre again, as shown in fig. 44 a. Owing to the force of the circulation, the circulating layer of water soon became coloured right through, until only a narrow strip running obliquely down remained untinged, *vide* fig. 44 b. At last this, too, disappeared, and the entire layer was coloured. The water layer beneath the warm centre remained entirely uncoloured, thus indicating that no interchange takes place between the circulating layer and that subjacent. On introducing a similar coloured solution into this lower layer, it appeared that the movement of the water here was altogether insignificant. The temperature of this layer was the same as that of the cold centre itself. The current leading from the cold to the warm centre was slightly warmer than the bottom

layer, but the warmest water in the tank was that which flowed from the warm centre to the cold.

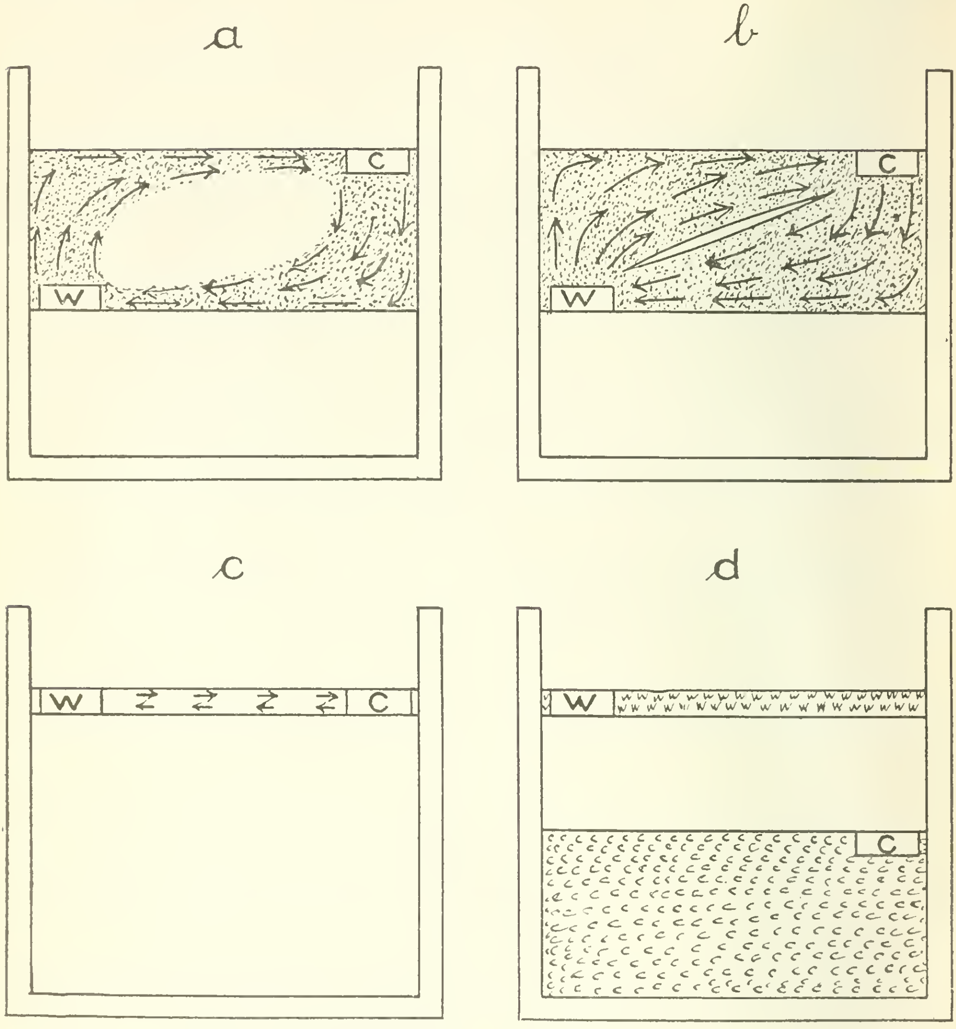


Fig. 44.—Experiment illustrating circulation of the Gulf Stream.

A further experiment was thereafter made with both warm and cold centres placed at the surface of the water. When stationary conditions had been reached, it was here found that a very slight degree of circulation was taking place between the warm and the cold centre, the entire remaining mass of water in the tank being motionless, as shown in fig. 44 c. Finally, the cold centre was placed at a lower level than the warm. In this case, as with the foregoing experiments, a highly intensive circulation at first arose throughout the whole of the tank, but as soon as this had given place to a stationary situation, it was seen that the entire mass of water in the tank remained altogether motionless. The water at a higher level than the lower side of the warm centre had then the same temperature as the warm centre itself, and that below the level of the top of the cold centre the same temperature as this latter, *vide* fig, 44 d.

From these experiments important conclusions may be drawn with regard to the Gulf Stream. The actual bottom water of the ocean does not participate in the circulation of this current, which affects only water within the depth to which heat is carried down by the vortex of the Sargasso sea. The Gulf Stream thus presents a well-defined, closed circulation with a warm surface current from the tropics to the Arctic ocean, and a cold, deep-water current in the opposite direction. It is at the surface of the water in the Arctic, and at the bottom of the Sargasso vortex in the south, that the physical changes take place which give rise to the circulation of the entire current. From the experiments referred to it is seen that these changes act in co-operation, the quantity of water heated in the tropics corresponding exactly to the amount cooled in the Arctic. Even when the warm and cold centres are placed at the same level, or the former at a higher level than the latter, this rule is strictly complied with. (In the last case, the quantity of water cooled and heated is nil, the centres being surrounded by water of their own respective temperature.) This remarkable adaptation of the physical processes is perhaps the most important factor in regulation of the condition of the sea.

From fig. 44 b it will be seen that if the Sargasso vortex did not exist, and the sea-water were only heated by the direct action of the sun's rays upon its surface, then there would be no Gulf Stream, but only a very slight surface current. The oblique strip in fig. 44 b corresponds to the lower surface of the Gulf Stream, which is likewise situated at a greater depth about its warm centre in the tropics than at the cold centre in the Arctic.

The experiments indicate, as a general rule, for the two complementary physical changes, that the process whereby the specific gravity of the water is reduced must take place at a greater depth than that which increases it, and that the greater this depth the more easily will a current develop. If, however, the two processes take place at the same level, or with the reduction of specific gravity at a higher level than the reverse process, then no current will be produced thereby. It is thus not all physical processes in the sea which give rise to ocean currents.

It may occasionally happen that two opposite physical processes at the same level enter into co-operation, and thus set up a current. This is accomplished by a massing of the products of the one process until the difference of level necessary for the propulsion of a current is reached. The Labrador current is itself an instance of a current originating in just this very way. The melting of the ice in the Arctic basin produces a mass of brackish water, which has to be carried away. This water therefore collects until it has formed a layer so deep as to be capable of forming a current, the volume of the latter then corresponding to the further production of brackish water beyond that point.

As to how far the Gaspé current should properly be considered as belonging to this last category is a question which can only be determined by further investigation. The physical process in which it originates is the mixing of St. Lawrence water with sea-water outside the mouth of the river. It is possible that this mixing process extends, owing to ebb and flow of the tide, down to a considerable depth. It may, however, take place at the surface, in which case the mixed water would only by accumulation attain a sufficient depth to give rise to a current, when the amount of water transported thereby would answer to the quantity of mixed water thereafter produced outside the mouth of the St. Lawrence.

The Gaspé current is one of the few ocean currents which may conveniently be observed and studied, as regards cause and progress, by hydrographical measurements at its point of origin, throughout its course, and at its termination. Such study is, moreover, of the highest importance, not least as a means towards the better comprehension of similar problems which present themselves in the case of other currents whose origin and progress are less easily discernible. The value of the Gaspé current in this particular respect has, as a matter of fact, already been manifested, the investi-

gations of Dr. W. Bell Dawson[1] upon this current and its effect on the circulation in the gulf of St. Lawrence having been of great assistance to me in the preparation of this chapter.

In order to demonstrate the effect of the wind upon the Gulf Stream, the following experiment was carried out. An elongated rectangular tank with glass walls

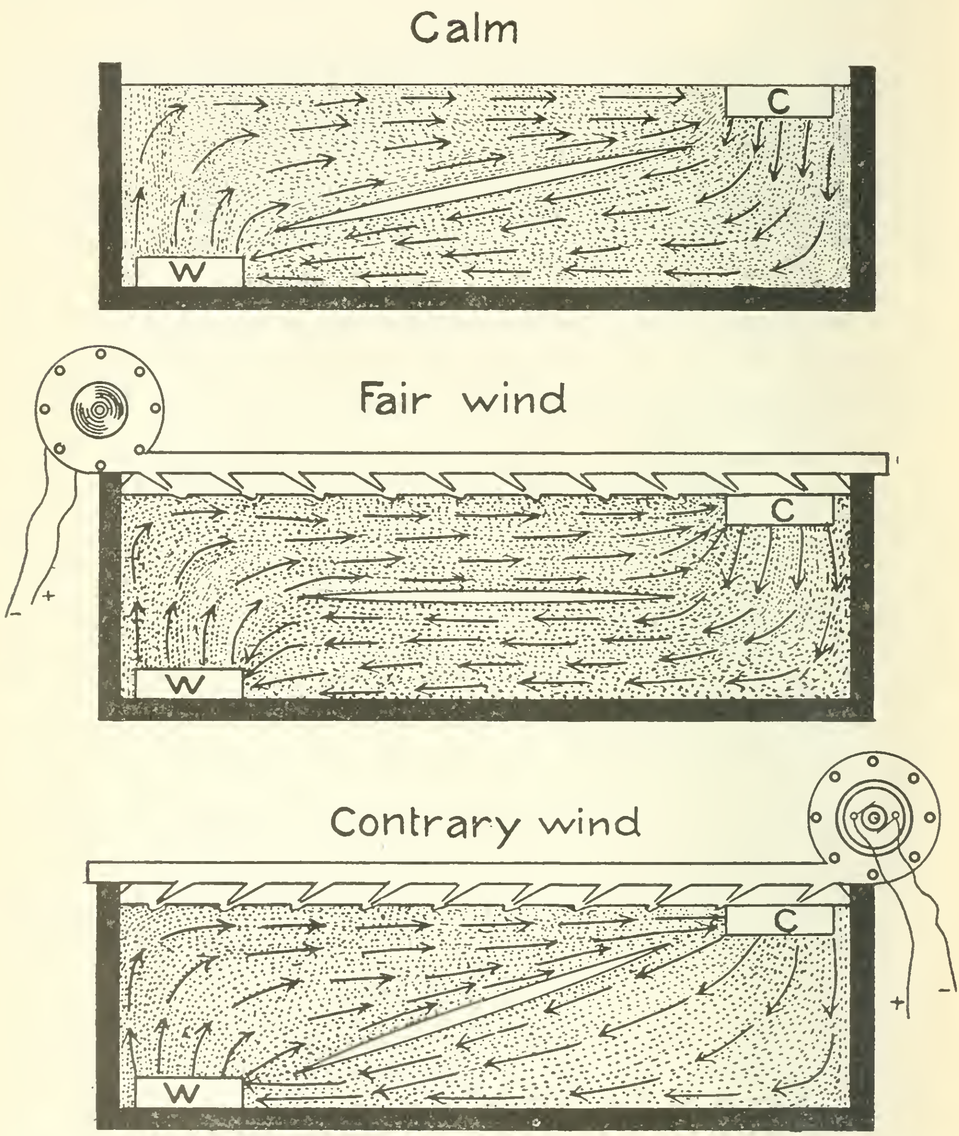


Fig. 45.—Influence of the wind upon the Gulf stream.

(*vide* fig. 45) was furnished with hot and cold centres, the former at one end of the tank, near the bottom, and the latter at the other, at the surface. The upper diagram in fig. 45 shows the circulation this produced. On introducing a coloured solution,

[1] *W. Bell Dawson.* Survey of Tides and Currents in the Canadian Waters. *Vide* series of Reports issued by the Department of Naval Service, Ottawa.

there appeared the oblique strip which separates the heated water from the cooled, answering to the under surface of the Gulf Stream in the sea. By means of an electric turbine, a current of air was then directed through a number of tubes set obliquely to the surface of the water, producing a very effective tangential wind action upon the same. The second diagram in fig. 45 illustrates the effect of the wind when blowing in the direction of the artificial stream answering to the Gulf Stream produced as above described. The oblique strip, corresponding the lower surface of the Gulf Stream, then approaches the horizontal, i.e., the Archimedean forces in the current are here highly weakened, and contribute only in a very slight degree to propulsion of the water. As a matter of fact, the strip can, by sufficiently increasing the force of the wind, be made to slope the opposite way, when the Archimedean forces will actually oppose the progress of the current. On the other hand, with a wind in the opposite direction to that of the current, as shown in the lowest diagram, fig. 45, the slope is increased, the Archimedean forces being then greatly augmented.

The meaning of this is not difficult to comprehend. The hot centre W produces a certain quantity of warm water, and the cold centre K a certain amount of cold each second, quite independently of the wind. By adaptation, consisting of change in temperature, a state of things is soon reached when the cold centre consumes warm water and produces cold at a rate per second exactly corresponding to the rate at which the warm centre consumes the cold and produces warm. The quantity of water flowing per second through any section of the current will be exactly equal to the amount of water thus transformed. Whether the current be subjected to the action of the wind or not, this quantity of water must flow on. In the case shown in the first diagram, fig. 45, the current is opposed only by the internal friction of the water itself, and the Archimedean forces have here only this resistance to overcome. In the second case, the progress of the current is aided to a high degree by the action of the wind. The result of this is, at first, an acceleration of the current; this, however, soon causes the oblique stratum to take up a more horizontal position, in consequence of which, the Archimedean forces are so diminished that their motive power only suffices to propel the requisite quantity of water when aided by the action of the wind. Finally, in the third case, where the forward movement of the water is greatly hindered by the wind, the current is at first retained, then, with the consequent increased slope, the Archimedean forces attain a higher degree of intensity, until at last they furnish motive power sufficient to propel the due quantity of water despite the resistance of the wind.

From this we see how insignificant is the part played by the wind as a motive power in currents of this nature.

11. BJERKNES' CIRCULATION THEORY.

The Bjerknes' theory of circulation, with the clear and profound insight which it displays, is in my opinion so eminently valuable an adjunct to the study of hydrographical phenomena that I have thought it necessary here to give a general idea of the principles contained therein, inasmuch as these bear directly upon marine conditions. I have endeavoured, in this survey, to keep to the simplest possible mathematical formulæ only; readers wishing to follow the entire process of deduction and examine for themselves the manner in which the results are arrived at, may refer to Bjerknes' own works on the subject, in particular to his comprehensive treatise on dynamic meteorology and hydrography, published by the Carnegie Institute, of Washington, U.S.A.

We may commence with Bjerknes' analysis of the Archimedean forces. As a result of this analysis it is shown that the measure of the forces in question may be taken as represented by the number of parallelograms formed in a hydrographic section by the intersection of the isobars with the isosteres. It is here presupposed that the figures in question are drawn for each whole unit of pressure or specific volume. Each

such parallelogram endeavours to bring about a rotary movement of the water, whereby the isosteric lines would be brought into the horizontal, *vide* fig. 46.

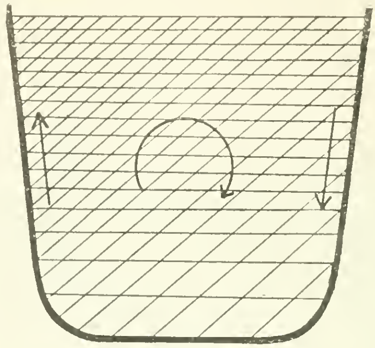


Fig. 46.—Bjerknes' diagram of the Archimedean forces in the sea.

It is interesting to pursue the study of this simple geometrical diagram so as to embrace the three dimensions. We have, then, in place of the isobars and isosteric lines shown in fig. 46, a series of isobar and isosteric surfaces, while the parallelograms become tubes, each presenting a parallelogram in section, these striving to turn the water round in such a manner as to render the isosteric surfaces horizontal. As the isobar and isosteric surfaces cannot terminate in the water itself, but must continue until they reach either surface or bottom, so also the isobar-isosteric tubes formed by intersection of the two must either continue until they reach one limit of the water or else turn back upon themselves. As each tube lies between two adjacent isobar surfaces, its course becomes horizontal.

These isobar-isosteric tubes are called solenoids. Each solenoid produces the same whirling effect in the water, and the number of solenoids is therefore a measure of the degree of intensity attained by the Archimedean forces.

The number of solenoids depends upon the number of isosteric surfaces; i.e., upon the stability of the sea-water, and upon the obliquity of the isosteric surfaces themselves. As the isosteric surfaces fall into a horizontal position, the solenoids disappear entirely. Consequently, the greater the stability of the water layers, and the greater the obliquity of the isosteric surfaces, the greater will be the number of solenoids.

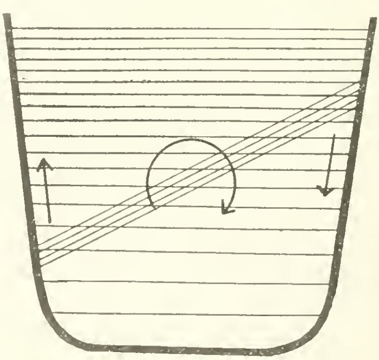


Fig. 47.—Solenoids in the separating surface between two water layers.

Where a homogeneous water layer rests upon another of higher specific gravity, there will be no isosteric surfaces within the layers; such will, however, be found in the separating surface between them. In this boundary surface, then, the solenoids will

be located, *vide* fig. 47. It is easy to find the number of solenoids in this case. If the specific volume of the upper layer be v_1, and that of the lower v_0, there will then be $v_1—v_0$ isosteral surfaces in the boundary surface. And if the pressure at the lowest point of the boundary surface be p_1, that at its uppermost point p_0, then these isosterical surfaces will be intersected by $p_1—p_0$ isobaric surfaces. The number of solenoids A will thus be $A = (p_1—p_0)\ (v_1—v_0)$ where $p_1—p_0$ indicates the slope of the isosteric surfaces, and $v_1—v_0$ the stability of the water layers. The number of solenoids is the product of these two factors.

In order to ascertain the effect of the solenoids upon the movement of the water, Bjerknes takes a closed curve composed of water particles in the sea, and calculates the product of the curve's length and the mean velocity of the water along its course. This product is called the circulation of the curve. Where the velocity of the water is not uniform at all parts of the curve, the circulation may be most easily arrived at by integrating the tangential velocity of the water along the curve for the whole length of the same.

$$C = \int u_t\, ds \qquad (4)$$

This integration may best be represented graphically by setting out the length of the curve, reckoned from any point, in a rectangular co-ordinate system, as abscissa, with the tangential velocity of the water as ordinates, and then, by means of a planimeter, measuring the extent of the surface between the curve thus produced and the abscissal axis. Fig. 48 shows the application of this method for calculating the circulation of a circular curve situated in a current. The current is here taken as flowing

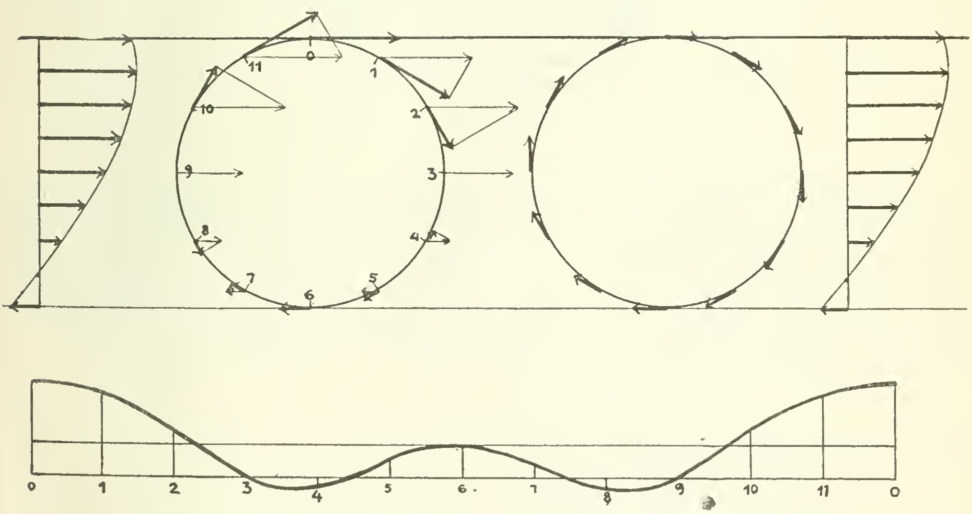


Fig. 48.—Method of calculating the circulation in a closed circulation curve in a sea current.

horizontally, at the velocities shown in the diagram on either side of the figure. The curve is first divided up into a suitable number of parts. At each point of division, the velocity of the water is marked off, and its tangential component along the curve constructed. In the diagram at the bottom of the figure, the length of the curve reckoned from the point 0 is set off as abscissa. At the points 0, 1, 2 of the abscissa, corresponding to the similarly designated point on the closed curve, the tangential velocities are thereafter marked off as ordinates. The area of the diagram is then measured with the planimeter, the part below the abscissa being of course taken as negative, and subtracted accordingly; this gives the circulation of the closed curve.

If we divide the circulation thus arrived at by the length of the curve, we obtain the mean tangential velocity along the closed curve. By marking this off on the diagram, we obtain in the horizontal line there dividing the same into two parts, so that the area above the line is equal to that below.

This mean tangential velocity may now be again applied to the original closed curve. Circle No. 2 in fig. 48 shows what is then arrived at, viz., the rotary movement of the water.

The circulation of closed curves in the sea thus affords a measurement of the rotation of the water. The translatory movement in the water is not discernible in the circulation. A closed curve in a current, where all the particles have the same velocity will always have a circulation $= 0$. By calculating the circulation, we thus obtain the pure rotary movement of the water, *vide* fig. 48.

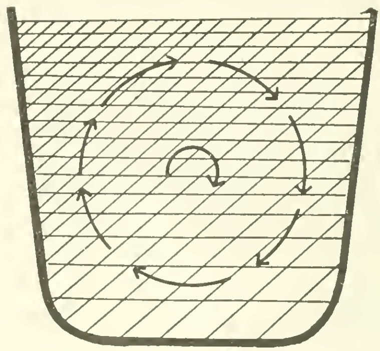


Fig. 49.—Relation between solenoids and circulation.

It now only remains to find the relation between the circulation C, and the number of solenoids A. To arrive at this, we lay out a closed curve in the section, fig. 46 (*vide* fig. 49), and calculate the circulation in the manner shown in fig. 48. This gives a certain value, C. This value is, however, not invariable, but is continually augmented by the rotary tendency of the solenoids. According to Bjerknes, the increase of circulation per second is equal to the number of solenoids within the closed curve. After the lapse of t seconds, therefore, the circulation of the curve will be

$$C = C_0 + A\,t$$

By derivation we then obtain,

$$\frac{d\,C}{d\,t} = A \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

indicating that the increment of circulation per second is equal to the number of solenoids. By means of Bjerknes formula for the relation between distribution of density in the sea and movement of the water, we can thus in the easiest possible manner calculate the latter from the former.

Obviously, the circulation is affected, not only by the distribution of density, but also to a very high degree by the earth's rotation. Each latitude circle of the globe has a considerable circulation owing to the earth's rotation. By a simple calculation, this will be found to be $C = 2\omega S$ where ω is the angular velocity of the earth, and S the area of the latitude circle. Bjerknes has shown, however, that this formula applies equally to any closed curve on the globe, if we take S as indicating the area given by

projection of the curve upon the equatorial plane; and, further, that the alternation in the circulation of such a closed curve per unit of time amounts to

$$\frac{dC}{dt} = 2\omega \frac{dS}{dt}$$

where $\frac{dS}{dt}$ indicates the alternation per second in the area of the curve's projection upon the equatorial plane. Where S is reduced, the curve assumes a cyclonic circulation, while when S is increased, the circulation will become anticyclonic.

Finally, the circulation is also influenced by the friction. For the effect of this, Bjerknes has introduced the symbol R. As both the earth's rotation and the friction as a rule oppose the distribution of density, Bjerknes gives the influence of both a minus sign, and writes

$$\frac{dC}{dt} = A - 2\omega \frac{dS}{dt} - R \ldots\ldots (6).$$

This formula contains all that influences the circulation of the water in the sea.

12. SOLENOIDS IN THE CANADIAN ATLANTIC AREA.

Bjerknes' circulation theory will, it may safely be said, play a prominent part in future oceanographical investigations, on account of the ease with which it may be applied to hydrographical observation material, and the clearness and direct practical value of the results thereby obtained.

Its chief importance in the immediate future will be as a system upon which to order and arrange the collecting of oceanographical observation material. The system requires, in this respect, certain conditions, of which those concerning the distribution of density and specific volume have been excellently fulfilled by Dr. Hjort's measurements in the Canadian waters, while those concerning the distribution of velocity have as yet proved impossible of realization.

I purpose, then, in the following pages to apply Bjerknes' circulation theory, as far as can possibly be done, to the present material, drawing such conclusions as may thence be arrived at, and finally indicating what yet remains to be done in order that the system may be utilized to its fullest extent, and by the gradual adaptation of measuring instruments, methods of observation, etc., directed towards the solution of still further oceanographical problems.

The weak point in the methods of observation hitherto in vogue is the system employed for measurements of velocities. Bjerknes' theory demands two kinds of measurements in this respect: one for the calculation of $2\omega \frac{ds}{dt}$ and the other for that of R. An instrument for the former already exists,[1] and all that remains here is to arrange the observations in such a manner as to render them suitable for the purpose of calculating the influence of the earth's rotation according to Bjerknes' theory. For the latter calculation, we have no suitable instrument as yet; it is, however, an easy matter to construct one, and to arrange the observations so as to furnish the requisite material for calculation of R.

As regards A, the material collected by Dr. Hjort from the Canadian waters is in this respect beyond question the best that has ever been obtained from the atmosphere and the sea. Hjort's idea was to procure the fullest possible survey of hydrographical conditions, spring and summer, in the North Atlantic area, and this, as it proved, coincided entirely with Bjerknes' requisition as to get two complete and simul-

[1] *Hans Petterson.* A recording current meter for deep sea work. Quarterly Journal of the Royal Meteorological Society, vol. XLI, No. 173, January, 1915.

taneous surveys of density conditions in the area. From a dynamic point of view, Hjort's measurements leave absolutely nothing to be desired.

In applying Bjerknes' theory to hydrographic observations, it will be well to keep to one thoroughly connected system of units, as, for instance, the centimetregrammesecond system. Where these units do not suit, other convenient units can always be arrived at by multiplying by suitable powers of 10. Pressure in the sea increases by very nearly 100,000 c.g.s. units for every metre depth. If therefore, we take as unit of pressure of 10^5 c.g.s. then the pressure will increase by one such unit for every metre depth. Such unit of pressure we may call a decibar. To the pressure of the sea-water should be added that of the atmosphere, amounting to about 10 decibars. In the following, however, we shall not have occasion to reckon with absolute pressures, but only with differences of pressure, and may therefore neglect this initial pressure, taking the pressure at the surface of the sea as a starting point. The depth in metres will then likewise serve to express the pressure in decibars; thus at 10 metres' depth, the pressure is 10 decibars, at 300 meters, it is 300 decibars, and so on. This identity of values will, as we shall subsequently see, serve greatly to simplify the graphical and numerical operations involved.

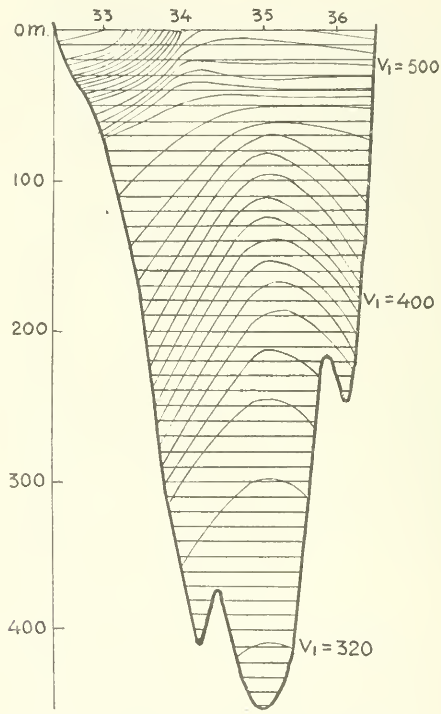


Fig. 50.—Isobars, isosters and solenoids in section IX.

For specific volume, it is convenient to take 10^{-5} c.g.s. as the unit. Then instead of writing, for instance, $v=0 \cdot 97261$, we take $10^5\ v=97261$, and as the two first figures in values for specific volume are always 97, and we have only to reckon with differences of the same, we can discard these, and write $v_1=261$. Thus in the case of specific volume, we have only to deal with three-figure values, which again serves to render the necessary calculations easier.

By thus taking the isobars as 10^5 times too far apart, and the isosteres 10^5 too close, we obtain cgs. solenoids.

Fig. 50 shows isobars, isosteres, and solenoids in section IX. The isobars have been drawn for each ten metres depth, and the isosteres, for each tenth unit of v. In fig. 50, then, each square contains 100 cgs. solenoids.

If now, in the isosteric secrions I-XX, plates VIII and IX we work out in a similar manner the isobars for each 1 metres depth, we obtain a good view of the distribution of the solenoids and their number throughout the entire area of investigation. Where the isosters have been drawn for each tenth unit of v_1, each square will contain 100 solenoids, but in the upper parts of the section, where they are taken for each fiftieth unit of v_1, there will be 500 solenoids to the square. It should hardly be necessary, however, to draw up in practice a linear system so simple as that of the isobars for each 10-metre depth; this may easily be imagined. On so doing, we obtain

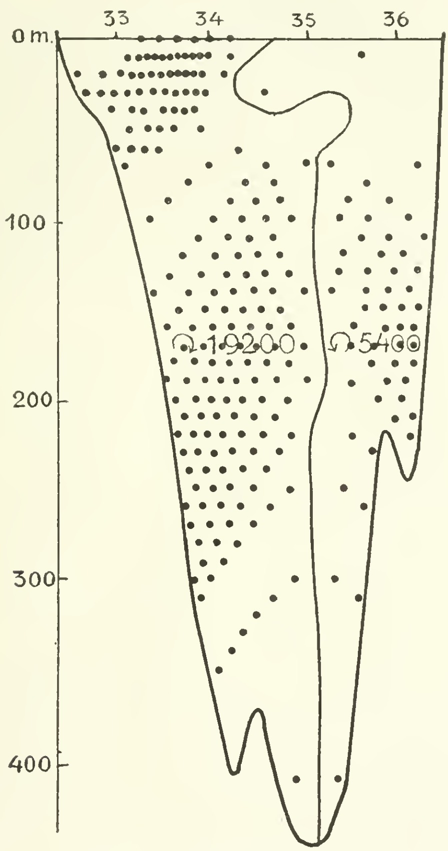


Fig. 51.—Solenoids in section IX.

from the isosteric sections I-XX, an immediate idea as to the position of the solenoids and their numerical values during spring and summer in the Canadian waters.

Another good way of showing the number and distribution of the solenoids is as follows: After drawing up the isobars and isosteres, the points of intersection between them are marked out, and both line systems then erased. This gives a system of points, each representing 100 solenoids. By counting the points, and multiplying their number by 100, we obtain the number of solenoids (*vide* fig. 51).

Each solenoid lies between, and is bounded by two adjacent isobar surfaces. Its course is thus pefectly horizontal, and its vertical extent amounts to exactly one

metre. Its breadth is considerably greater, being equal to the horizontal distance between the isosteric surfaces. And as it is always bounded horizontally by the same isosteric surfaces, its course may be arrived at by drawing upon a chart the isosteric lines for the level at which the isosteres are situated. This chart will then also give the course and number of all other solenoids in a water layer of one metre's thickness at the same level.

There are thus many ways of drawing up graphic presentments of solenoids. We need not, however, here devote more time to these, but may pass directly to the problem of calculating, in the simplest and surest manner, their number, A. The number of solenoids between two stations in a horizontal water layer of one metre is obviously equal to the difference in specific volume between the two stations at the level in question. Our first task, then, will be to calculate this difference. Let us, for instance, calculate the solenoids between the stations 34 and 35 in section IX. First of all, we note down the depth at which the water samples from each station were taken. This is shown in the first column of table 3. The second column shows the specific volumes for station 34, and the third those for station 35. The fourth column contains the differences between the specific volumes; i.e., the number of solenoids in a water layer one metre thick situated between the two. The signs before the figures shows the rotary tendency of the solenoids. In the vertical, with greater specific volume, the water will strive to move upwards; where it is less, the tendency will be downwards. The solenoids will thus endeavour to bring about such a rotary movement of the water as should cause it to rise at station 34 and sink at station 35. This is what the signs here show. The signs have thus a certain relation to the order in which the stations appear in the tables. If the stations be reversed, the signs will be changed.

The next operation is to calculate the number of solenoids in those rectangles in the sea which are bounded by the two stations and the different depths. For this purpose, we calculate, from the figures in column 4, mean values for 1-metre water layers at the different intervals of depth. These are shown in column 5. Multiplying by the depth of the intervals in metres, we obtain the desired number of solenoids, as shown in column 6. By this simple and rapid means, it is possible to calculate the number of solenoids between any pair of stations in the area where observations were carried out simultaneously, or nearly so, however great may be the distance between the stations. The number of solenoids between a station in the Arctic and another at the equator may be calculated as easily as the corresponding value for two stations in the gulf of St. Lawrence. And this is just one of the features which render Bjerknes' circulation theory so useful in discussing the greater phenomena of the sea.

If the two other pairs of stations in section IX, 33-34 and 35-36, be treated in the same manner, we shall then have obtained all the solenoids in section IX, which can be found from the hydrographical observations there carried out. Fig. 52 shows the number of these, and the areas within which they are found. Here, then, we have yet another method of presenting solenoids. Of the various methods in which this can be done,those shown in figs. 50 and 51 are clearer, but that in fig. 52 is more correct.

By the method shown in table 3 and fig. 52, we obtain only the solenoids which are found between the hydrographical stations, but not those lying outside. For the latter, the methods shown in figs 50 and 51 are more convenient, permitting, as they do, extrapolation so as to include also the area outside the stations. This extrapolation method cannot well be applied to the more exact procedure shown in fig. 52. The extrapolated values might also be of so little value as to leave no reason for preferring, on this account, figs. 50 and 51 to fig. 52. The numerical method shown in table 3 should therefore be regarded as the best way of arriving at the number of solenoids.

On adding up the figures in column 6 of table 3, we obtain the total number of solenoids between station IX 34 and IX 35. The addition may be made either from above or from below. The latter is preferable, the water at greater depths being as a

rule calmer, with fewer solenoids. It is therefore advisable to commence from below, with O, and then let the perturbations in the upper water layers appear through the greater number of solenoids there present. The lowest level from which measurements are available will then be the starting point, and the number of solenoids will be shown as from this level to all levels above. Column 7 in table 3 shows the sums of the solenoids.

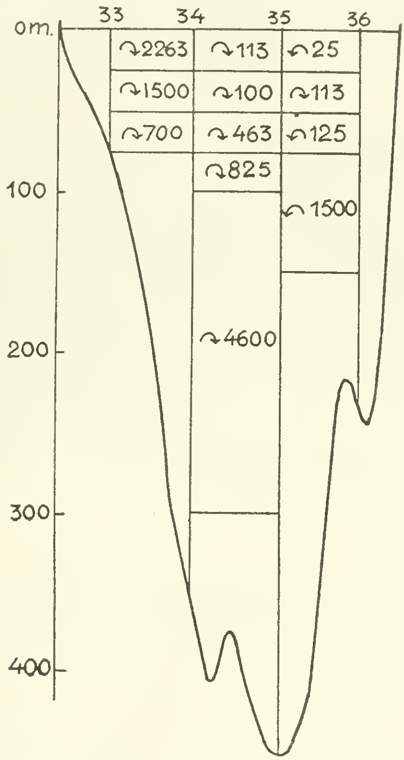


Fig. 52.—Amount of solenoids in section IX

Obviously, the number of solenoids as thus calculated will depend upon the distance between the stations. The farther one station lies from another, the greater will generally be the number of solenoids found between them. In order to obtain a correct idea as to the solenoid intensity in the sea, it will therefore be best to reduce the number of solenoids to a certain normal horizontal distance, e.g. 100 km. The distance between station 34 and 35 in section IX is 62 km. By multiplying the number of solenoids by 100 and dividing by 62, we obtain the normal values for this particular case. This operation should be carried out with the figures in columns 4 and 7 of table 3. Columns 8 and 9 contain these normal values. The figures in column 8 show the number of solenoids in 1 metre layers for 100 km., i.e. affords a measure of the variation in density in a horizontal direction, and column 9 the number of solenoids per 100 km. from the different levels of measurement down to the greatest depth from which observations are available. The figures in column 8 furnish the best means of indicating the intensity of the Archimedean forces in the section, while those in column 9 best show the effect of the forces in question.

Coming now to the question of publishing these different values for the number of solenoids between all pairs of stations in Dr. Hjort's sections, we may begin with

eliminating the first two columns of table 3, these being contained in table 1. Columns 4 and 8 are left unaltered, column 5 is superfluous, and in columns 6, 7, and 9, the last figure of each value should be discarded, partly as having no real importance, and partly as rendering the values in question unnecessarily awkward to handle in calculation. This done, the solenoids in these columns are expressed in 10 cgs. Column 9 may also be said to indicate cgs. solenoids per 10 km. Table 4 shows the simpler form given to table 3 by this process. Table 5 contains the number of solenoids according to the scheme in table 4 for all pairs of stations in Dr. Hjort's sections. The heading above each pair of stations indicates the distance between them, and the approximate mean depth of the intervening area.

13.—INFLUENCE OF THE EARTH'S ROTATION UPON CIRCULATION.

The influence of the earth's rotation upon circulation makes itself apparent in a very simple manner in the atmosphere. When the air at any point commences to rise upwards, and the surrounding air in consequence pours in from all quarters to replace that which has risen, then this indrawn air will, as it approaches the centre of ascent, develop a marked cyclonic circulation. Thus in fig. 53, taking O as the centre of ascent, and A as a closed curve composed of air particles about the same, then, at the commencement of the movement, the velocity will be directed towards the centre, and the curve will have no circulation. After a certain lapse of time, the curve will, on account of the centripetal movement of the air, have contracted to the position b, at the same time developing a cyclonic circulation. The circulation increment per second is, according to Bjerknes:—

$$\frac{dC}{dt} = -2\omega \frac{dS}{dt} \quad \ldots\ldots\ldots \quad (7)$$

ω being here the angular velocity of the earth, and S the area of the closed curve's projection upon the equatorial plane. And as S decreases, C is increased, *vide* fig. 53.

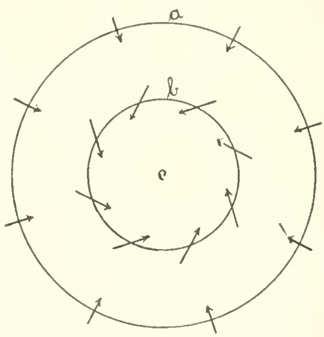


Fig. 53.—Cyclonic circulation produced by the earth's rotation.

In the sea, the movement of the water is to a very high degree restricted and deformed by the shape of the water basins. There is, therefore, in this case, no regular concentric movement about the centre of descent. In spite of this, however, we still find here a marked cyclonic circulation, which, in the Arctic ocean, where the Gulf stream sinks down, and in the waters south of Newfoundland, where the Labrador current disappears, attains very considerable dimensions.

The vertical velocities in the sea are insignificant in comparison with the horizontal, and we may therefore, in calculating the circulation, neglect the former

altogether. We then obtain the area S of the projection of the closed curve upon the equatorial plane, by projecting the curve upon the level of the surface of the sea, and multiplying the area σ thus obtained by the sinus of the latitude φ i.e.,

$$S = \sigma \sin \varphi$$

Inserting this value for S in (7), we obtain

$$\frac{dC}{dt} = -2\,\omega \frac{d\sigma}{dt} \sin \varphi$$

And if, again, we insert in this formula the value for $2\,\omega$, viz., 0.0001458, we obtain

$$\frac{dC}{dt} = -0.0001458 \frac{d\sigma}{dt} \sin \varphi \quad \dots\dots\dots\dots \quad (8)$$

This formula (8) is specially suited to the treatment of measurements of velocity in the sea, as these measurements always give the horizontal components of the velocities; i.e., the projection of the direct velocity upon the level of the sea's surface.

No measurements of velocity were made during Dr. Hjort's expedition in the Canadian waters, and we have therefore no opportunity of applying the Bjerknes' formula for rotation of the earth to observations here in the regular manner above described. We have therefore recourse to another, more indirect application of the same, we can reckon out the velocities which the water should have in order to fulfil the requirements of Bjerknes' equation, with the distribution of density as found by Dr. Hjort. By this means, we obtain indirectly an idea as to the movement of the water within the area of investigation.

In Bjerknes' equation (6), the first and last terms are small in comparison with the two intermediate ones. As a first approximation, therefore, we may disregard the former and write

$$A = 2\,\omega \frac{dS}{dt}$$

or, instead of this, taking the projection of the closed curve upon the level of the sea

$$A = 0.0001458 \frac{d\sigma}{dt} \sin \varphi$$

From which we obtain

$$\frac{d\sigma}{dt} = \frac{A}{0.0001458 \sin \varphi} \quad \dots\dots\dots\dots\dots\dots \quad (9)$$

In this formula, the right side is determined by the distribution of density, and the left by the movement of the water. The right side is known from table 5, which shows A for a large number of closed curves throughout our area of investigation. In consequence, therefore $\frac{d\sigma}{dt}$ i.e., the deformation of these curves, due to the movement of the water, will likewise be known. By this means, we are able to calculate the movement of the water from the distribution of density.

Obviously, however, we cannot by this means obtain the whole movement of the water. We might imagine, for instance, a closed curve composed of water particles in a current, following the current in such a manner that the area of its projection upon the level of the sea's surface would not be altered thereby. This would, then, according to formula (9), contain no solenoids at all. But this does not necessarily imply that the water in which the curve appears, and of which it forms a part, has no great velocity. In other words, the formula (9) gives, not the absolute velocity of the curve, but only its deformation, i.e., the extent to which its one part moves relatively to the other.

The closed curve should therefore be selected in such a manner as to give the least possible degree of movement in the one part. As equation (9) gives the movement of

the other part relative to this, it will in this case give the actual velocity of the same. Now, the movement of the water at great depths is inconsiderable, the greatest velocities occurring in the upper water layers. We therefore select the closed curve in such a manner that its one part is situated at the greatest possible depth, and calculate the velocity of the other, upper portion, relatively to this deeper part.

The values in table 5 best suited to this calculation are those indicated as ΣA_{10km}. This column gives A for closed curves having their vertical parts situated at a distance of 10 km. apart and with the one horizontal portion situated at the greatest depth from which measurements are available. Taking this lower horizontal portion as inmobile, and the upper as moving at right angles to its own longitudinal direction with a velocity of u cm. per second, then obviously the increment of area in the projection of the curve upon the level of the sea's surface amounts to

$$\frac{d\sigma}{dt} = 10^6 u$$

per second, 10 km. here representing 10^6 cm. Inserting this value for $\frac{d\sigma}{dt}$ in (9), we obtain:

$$u = \frac{A}{145 \cdot 8 \sin \varphi} \quad \ldots\ldots\ldots\ldots\ldots \quad (10)$$

For the latitude $= 43°19'$, which falls within our area of investigation, is

$$145 \cdot 8 \sin \varphi = 100$$

and in consequence:

$$u = \frac{A}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

i.e., the ΣA_{10km}. columns in table 5 give the velocity in hundredths of a cm. per second. We need then only cut off two decimal points from the figures in this column in order to obtain the velocity in cm. per second.

In order to comprehend what is given in formula (11) we may consider a current in the sea flowing over a substratum of still water. Owing to the rotation of the earth, the current will veer off to the right until it encounters a coast, which it will then follow, still pressing towards the right, i.e., setting in towards the coast. In consequence of this pressure, the current will become deeper near the coast than farther out; i.e., the separating surface between the current and its substratum of heavier water will lie obliquely. In this surface, then, there will be a number of solenoids running in the longitudinal direction of the current. By taking a hydrographical section across the current, and treating the observations according to the scheme in table 3, we obtain the number of these solenoids. Formula (11) now shows, that if 10 km. breadth of current contain 100 solenoids, then the current will flow at a velocity of 1 cm. per second; if 1,000 solenoids, the velocity will be 10 cm. per second, and with 10,000 solenoids, the velocity of the current will be one metre per second. If the number of solenoids be 6,728, the volocity of the current will be 67·28 cm. per second.

This simple relation is, of course, strictly speaking, valid only for latitude 43° 19'. For other latitudes, we can obtain from table 6 the number of solenoids per 10 km. breadth of current which will give a velocity of 1 cm. per second. By dividing the values for number of solenoids obtained through the hydrographic measurements by the figure in table 6 corresponding to the latitude of the station, the due allowance for

geographical situation will be made. The last column in table 5 contains the velocities thus calculated.

As regards direction of the current, this will be easily understood from the foregoing. The lighter surface water is pressed over to the right by the earth's rotation. Placing myself, for instance, in the section so as to have the lighter water on the right hand, and heavier on the left, I am then facing in the forward direction of the current.

It will also be evident from the foregoing, that the method in question gives only the component for current velocity in a direction at right angles to the section. This, however, is in the present case of but slight import, as Dr. Hjort has for the most part taken his sections in such a manner as to have them almost at right angles across the currents found. Dr. Hjort's measurements are, from a dynamic point of view, ideal in this respect.

In table 5, eight points of the compass have been used to designate the direction of the current. As usual, in dealing with ocean currents, the letter indicates the direction towards which the current flows. Thus *E*, for instance, denotes a current flowing from west to east.

Plates XIV and XV have been drawn up from the figures in the last column of table 5. The former gives the calculated velocities for spring, the latter for summer, 1915. From the intimate relation of these velocities to the number of solenoids (*vide* table 5), it follows that Plates XIV and XV also afford the best possible graphic presentment of the distribution of solenoids throughout the area of investigation.

14.—INFLUENCE OF FRICTION UPON CIRCULATION.

The influence of friction *R* upon the circulation of a closed curve, may be calculated in two different ways; either directly, from measurements of velocity taken for the purpose, or indirectly, by means of Bjerknes' equation for circulation, all the terms of this being known with the exception of R.

In the former case, three uniform current meters are set out on one and the same line, with say 5 metres vertical interval between each two, with which systems of instruments measurements are then taken at the different depths. From the measurements thus obtained, the parabolas for diagram of velocity are then constructed, and from these again the acceleration of the frictional force can be calculated (chapter 9). By integration of the tangential component for this along the closed curve, we obtain *R*.

In the second case, we have, according to (6),

$$R = A - 2\,\omega\,\frac{d\,S}{d\,t} - \frac{d\,C}{d\,t}$$

When the movement is stationary, $\frac{d\,C}{d\,t}$ disappears, and we have,

$$R = A - 2\,\omega\,\frac{d\,S}{d\,t} \quad \dots\dots\dots\dots\dots \quad (12)$$

If the closed curve lies along a stationary current, then $2\omega\,\frac{dS}{dt}$ will likewise disappear, and we obtain

$$R = A \quad \dots\dots\dots\dots\dots\dots \quad (13)$$

With this formula, it is a very simple matter to calculate the influence of friction upon the circulation, as also the acceleration of friction in a stationary current. As an example, we may take the Gulf Stream. A closed curve along this will include 150,000 solenoids, and consequently, in the Gulf Stream the retarding influence of the friction upon the circulation will amount to

$$R = 150{,}000 \ \frac{\text{cm.}^2}{\text{sec.}^2}$$

On dividing this figure by the length of the closed curve, $15 \cdot 10^8$ c.m., we obtain the mean value for retarding acceleration of friction for all water particles in the Gulf Stream,

$$f = 0 \cdot 0001 \ \frac{\text{cm.}}{\text{sec.}^2}$$

As a second example, we may take a closed curve along the Gaspé current at the surface, and at 60 metres depth, between Dr. Hjort's stations X 31 and XIII 38. On calculating A for this, according to the scheme shown in table 3, we find that the number of solenoids is 10880. For this, again, according to (12),

$$R = 10880 \ \frac{\text{cm.}^2}{\text{sec.}^2}$$

The length of the closed curve, via North, Cape Breton island, amounts to $2 \cdot 10^8$, i.e.,

$$f = 0 \cdot 00005 \ \frac{\text{cm.}}{\text{sec.}^2}$$

It is surprising that the retarding effect of friction upon ocean currents should be so great as this. If the solenoids ceased to operate, then the velocity of the Gulf Stream would be diminished by 1 cm. per second per 3 hours, and the Gaspé current by 1 cm. per second every 6 hours; in other words, save for the solenoids, currents of this nature would soon come to a standstill. We realize, then, the fundamental importance of the solenoids for propelling ocean currents.

If the closed curve be drawn *across* a stationary current, then R disappears, and (12) in consequence, gives place to

$$2\,\omega \ \frac{d\,S}{d\,t} = A \quad \ldots\ldots\ldots\ldots \quad (14)$$

by means of which formulæ we can calculate the movement of the water from the solenoids, see table 3 and plates XIV and XV.

These two formulæ (13) and (14) are, as hydrography now stands, the most important mathematical means for dynamic treatment of hydrographical observations.

In applying these formulæ, it is necessary to see that the conditions for which they are intended to apply are fulfilled. One disturbing factor which has to be reckoned with is the screwing movement of the water in a current. Owing to this, the influence of the earth's rotation does not altogether disappear in the case of closed curves lying in the longitudinal direction of a current. The part of such curves which is situated at the surface, is, by this screwing movement, carried towards the right, and we may easily find that the earth's rotation will therefore exert a retarding influence upon the current. The retardation calculated by formula (13), therefore, should not be ascribed exclusively to friction, as a part of it will be due to the earth's rotation. The more stable the layers in a current are, however, the

less chance will there be for this screwing movement of the water to develop, and the more insignificant the correction of formula (13) owing to rotation of the earth. On the other hand, where the water in a current is homogeneous, the screwing movement will develop to a greater degree, and there is then the risk that formula (13) may give too high values for R.

Formula (14) will likewise require to be corrected for the same reason. The screwing movement of the water is naturally opposed by the friction, and the influence of the friction upon the circulation does not therefore altogether disappear in the case of closed curves drawn transversely across a current. In such curves, then the earth's rotation will have two forces to overcome; that of the solenoids, and that of the friction. Thus the velocities calculated according to (14) from the solenoids alone will be too low; i.e., the values for velocity given in table 5 and plates XIV and XV will be too small. The friction, on the other hand, will have no effect upon their direction. By increasing these calculated velocities slightly, they can thus be made more correct viz., the less stable the water layers are the more the velocities will require to be increased.

The most disturbing influence, however, which affects the velocities calculated from formula (14) is that of the wind. The friction exerted upon the surface of the water by wind corresponds to a very considerable value of R. This will naturally be variable to a very high degree, but the direction in which it takes effect, and its nature generally, will of course depend rather simply upon the direction of the wind. By taking a few simple cases as examples, we may gain some idea as to the effect of wind upon the distribution of density in a current, and the velocities thence obtained according to formula (14).

(*a*) *Wind blowing in the forward direction of the current.*—In this case, the velocity of the surface water will be increased, and the water in question consequently be thrown off with greater force than previously to the right. In a section across the current, the isosteres will become more vertical, and the number of solenoids, A, greater. The calculated velocities will thus become greater, which agrees with the increased velocity due to the action of the wind. In this instance, then the effect of the wind will not greatly disturb our calculations according to (14).

(*b*) *Wind blowing directly against the current.*—The surface water will here be retarded, and the force with which it veers off to the right will be diminished. The number of solenoids in a section across the current will be less, and thus the velocities calculated from the same will likewise be lower, agreeing, again, with the actual decrease in velocity due to the opposing action of the wind. In this case also, then, the disturbing influence of the wind upon the calculations according to (14) will be but slight.

(*c*) *Wind blowing crosswise to the current, and in a shoreward direction.*—The surface water is here driven with great force to the right; the isosteres stand on end, and the number of solenoids in a section across the current will be abnormally increased. The velocities calculated from the solenoids according to (14) will therefore here be too great.

(*d*) *Wind blowing crosswise to the current, in a seaward direction.*—With a slight wind, the number of solenoids will be reduced, and the velocities thence calculated according to (14) too low. With a stronger wind, the entire current may be forced away form the shore and out to sea. This gives rise to a highly abnormal distribution of density and of solenoids, *vide* fig. 54 a, which on applying formula (14) gives the distribution of velocities shown in fig. 54 b. This is here so abnormal that it does not

correspond in any way to the actual movement of the water. Dr. Hjort's section IV is a good example of such abnormal distribution of density.

By simple discussions of this kind one may soon become familiar with the various phases which the state of the sea may assume, and can thus learn to determine the causes by which they are produced.

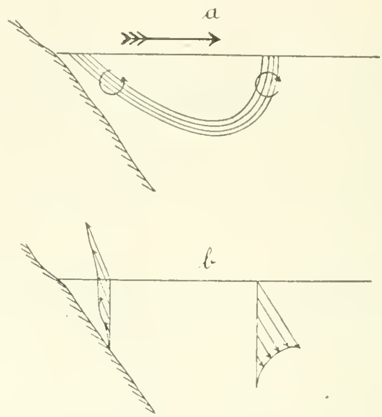


Fig. 54.—Distribution of density and calculated velocity according to formula (14) with offshore wind.

15. THE ACCELERATION OF CIRCULATION.

Let us imagine the sea and atmosphere in perfect calm and equilibrium. The isosteres and the isobars coincide with each other, and with the level surfaces of gravity, so that no solenoids exist.

In a part of this motionless sea, some physical process then takes place, whereby the specific gravity of the water there is altered. This gives rise to a local deformation of the isosteric surfaces, which now no longer coincide with the isobars, but intersect the same. The solenoids thus called into play then set the water in motion, according to the formula

$$\frac{d\,C}{d\,t} = A$$

At the commencement of this movement, therefore, the acceleration of the circulation $\frac{d\,C}{d\,t}$ will be equal to the number of solenoids.

As the velocity of the water increases, the resistance of friction R makes itself apparent. We have then

$$\frac{d\,C}{d\,t} = A - R$$

There R increases more and more, until at last it equals A. Then, according to the formula, $\frac{d\,C}{d\,t}$ disappears, and the movement becomes stationary. This is the sign of permanent currents, originating in and maintained by a perpetual physical change taking place in the sea water, such as the Gulf Stream.

The earth's rotation, however, also exerts a certain influence upon the circulation of the water. When the solenoids have set the water in motion, it is forced over to the right by the rotation of the earth. This pressure is augmented as the velocity of the water increases. Consequently, the rapidly moving surface water in a current is urged more forcibly to the right than the slower-moving water at greater depths, so that the total movement of the water mass will be a screwing one. And a transverse section across the current will therefore reveal a circulation taking place within the same. For this, the acceleration of circulation will be

$$\frac{dC}{dt} = 2\,\omega\,\frac{dS}{dt}$$

This circulation is itself opposed by the friction, wherefore

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - R$$

As the circulation is increased, the opposing force of the friction will likewise be augmented, until the influence of the latter will attain a magnitude equal to that of the earth's rotation. Then $\frac{dC}{dt}$ will disappear, and the circulation become stationary.

If the water of the current be in stable layers, then a system of solenoids will arise in the section across the same, and will, like the friction, oppose the influence of circulation occasioned by the earth's rotation. In this case, then,

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - A - R$$

Where the water is very stable, these reactionary solenoids may altogether arrest the circulation in the cross section. Then R will also disappear, and we have

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - A$$

The number of solenoids increases until it attains the same value as the influence of the earth's rotation, whereby $\frac{dC}{dt}$ disappears, and a stationary situation sets in. It is on such a state of things that rates XIV and XV have been based.

In all the cases here described, the acceleration of circulation $\frac{dC}{dt}$ increases rapidly at first from its value nil when the sea is at rest, reaches a maximum, and then declines asymptotically towards nil, when stationary conditions are reached. Fig 55a shows this variation of $\frac{dC}{dt}$ in course of time.

If the physical change in the water which gave rise to the current be of temporary nature, then the number of solenoids thus produced will gradually decrease, the current meanwhile progressing by inertia. The effect of friction will then be superior to that of the solenoids, and $\frac{dC}{dt}$ will be negative. As the physical changes gradually cease, the final state will in this case be that of calm and equilibrium. Fig. 55b shows the variation in the acceleration of circulation for a casual and temporary current of this nature.

It may also happen that the water, through inertia, flows too far. This gives rise to a system of solenoids the reverse of the original, and tending to turn the current, and so drive the water back. If this reverse movement, in its turn, carry the water too far, then a new solenoid system, corresponding to the original one, will again arise, turning the current once more in its original direction. This may be repeated several times.

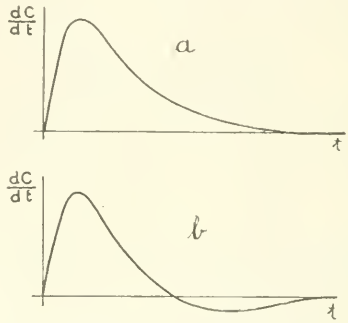


Fig. 55.—Alteration of circulation acceleration on the appearance of a) a permanent current b) a casual and temporary current.

The alteration in the acceleration of circulation will then become periodical, *vide* fig. 56.

From the foregoing, it will be seen that the sea is continually striving towards a state where $\frac{dC}{dt}$ approaches nil, *i.e.* the three terms on the right side of Bjerknes circulation equation endeavour to adapt themselves one to another in such a manner that their sum shall be nil. This would also take place, were it not for the fact that one or other of them is from time to time subjected to disturbance which alters its magnitude. This disturbance may be of various sorts. A physical change in the water, as for instance that brought about by the heat of the sun, or by the melting of ice, will alter the value of A. If a current veers off owing to the topography of the sea basin, then $2\omega \frac{dS}{dt}$ will be altered. The action of the wind exerts a great influence upon R, etc. After each such disturbance $\frac{dC}{dt}$ attains a maximum, decreasing afterwards, however, towards nil. Where the stability of the water layers is very great, as in the gulf of St. Lawrence, this decrease may take place so forcibly that $\frac{dC}{dt}$ passes beyond zero and becomes negative, thereafter altering periodically with decreasing amplitude, *vide* fig 56. The greater the stability of the water layers, the more rapidly will these oscillations take place.

Such oscillation also, of course, take place in the surface movement of the water, and would appear to be particularly frequent in surface currents occasioned by the wind; also, other surface currents however arising from different causes, doubtless oscillate in the same way. As the water at any point of the surface can, at a given

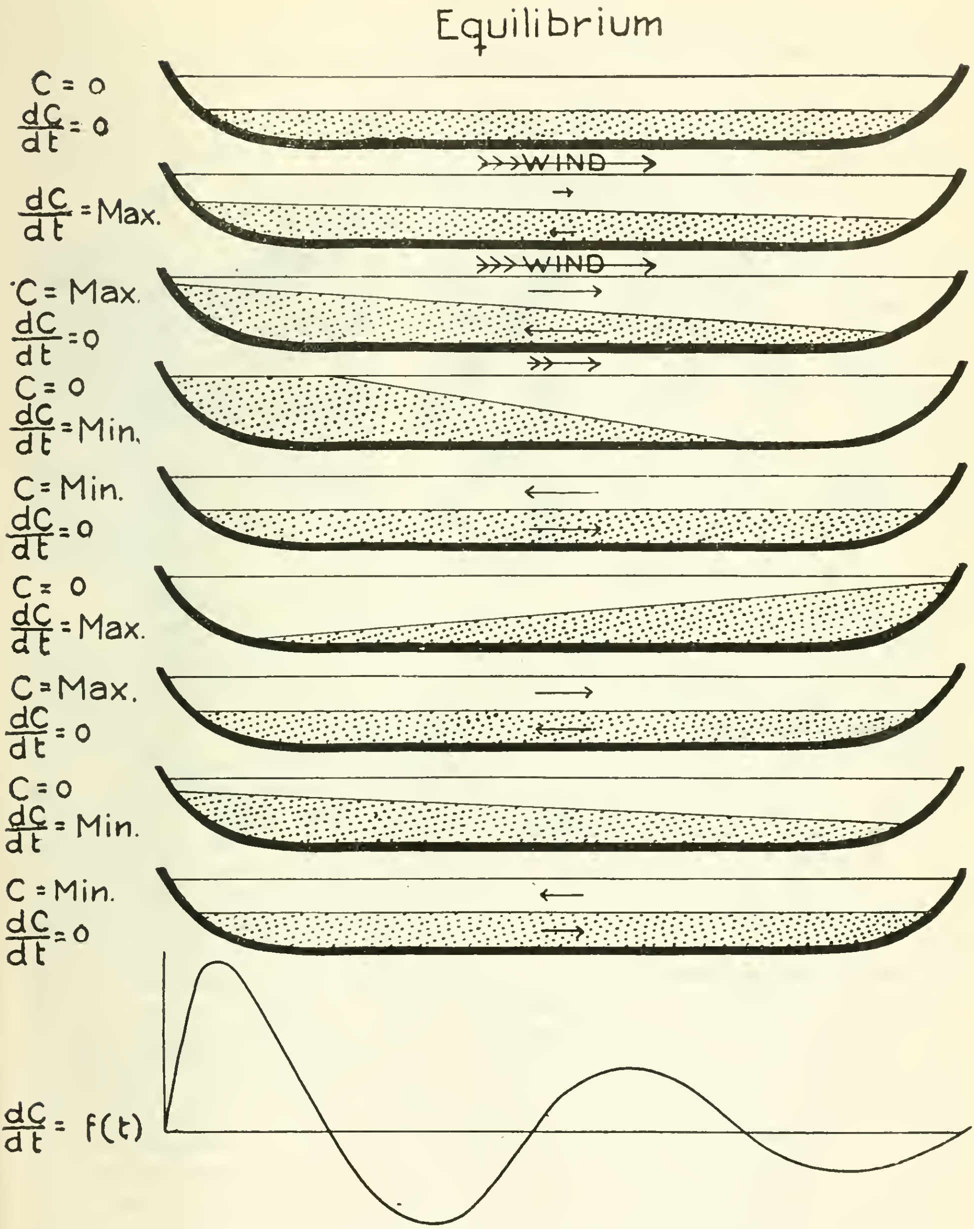


Fig. 56—Submarine seiches occasioned by brief but violent gales.

movement, have but a single direction of movement, it follows that the lines of current for surface water must answer to the equation

$$\frac{dy}{dx} = f(xy)$$

where x an y are the geographical co-ordinates of the sea's surface. For

$$\frac{dy}{dx} = sin\ (ax + by)$$

we obtain the courses of the current shown in fig. 57.

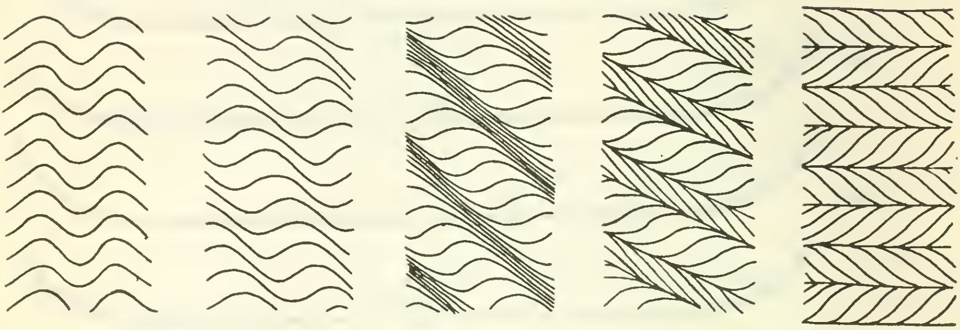


Fig. 57.—Oscillation of surface water, in area with water layers in stability.

The existing material of simultaneous measurements of velocity in the sea is unfortunately too small to permit of our verifying the current course here obtained by mathematical means. The meteorology is in this respect far more favourably situated, owing to the large number of stations from which the direction of the wind is observed simultaneously. And it is then a very simple matter to discover the existence of such oscillations. Figs. 58 and 59 serve to illustrate this. Fig. 58 shows direction and force of the wind, with distribution of atmospheric pressure on January 7, 1902, at 9 p.m. At a first glance, the direction of the wind would appear to be highly irregular, not only in comparison between the various stations, but also when compared with the regular course of the isobars. On drawing up the courses of the wind however (*vide* fig. 59) we find that the directions taken by the wind form part of a highly regular, and strongly oscillating wind system. Very much the same thing doubtless takes place in the sea. The observations of velocity, which at a first glance appear most irregular, might possibly turn out to be in actual fact, very regular and uniform, if only we could discern the oscillating system to which they belong.

Naturally, it will be out of the question to procure a network system of stations at sea as close as that for simultaneous observations on land. This would require too great a number of vessels. It would seem reasonable to ask, however, if the facility with which it is possible to ascertain conditions in a vertical direction in the sea, might not compensate for the greater facilities on land in a horizontal direction. Where the surface water, owing to the oscillating movement, is massed together, the surface layer must be thicker than where it flows apart. It should be an easy matter to construct an instrument for indicating, for instance, the depth of an isotherm situated not too far down, while the vessel lay motionless at a hydrographical station. If the depth be constant during the time the measurements are being made, then the sea is not in oscillation, and the hydrographical observations may be taken as representative of the place and season; if, however, the depth varies, then periodical oscillations take place, and the hydrographical conditions ascertained by measurements

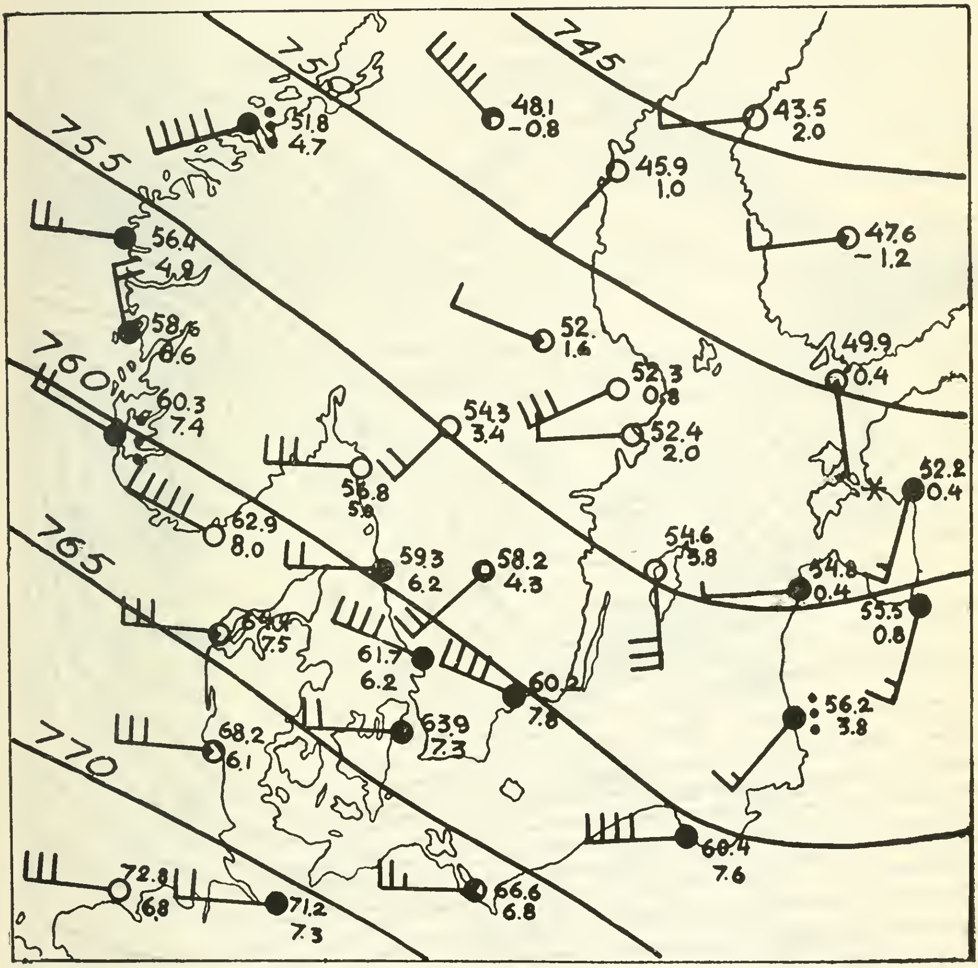


Fig. 58.—Direction of wind on 7 January, 1902, at 9 p.m.

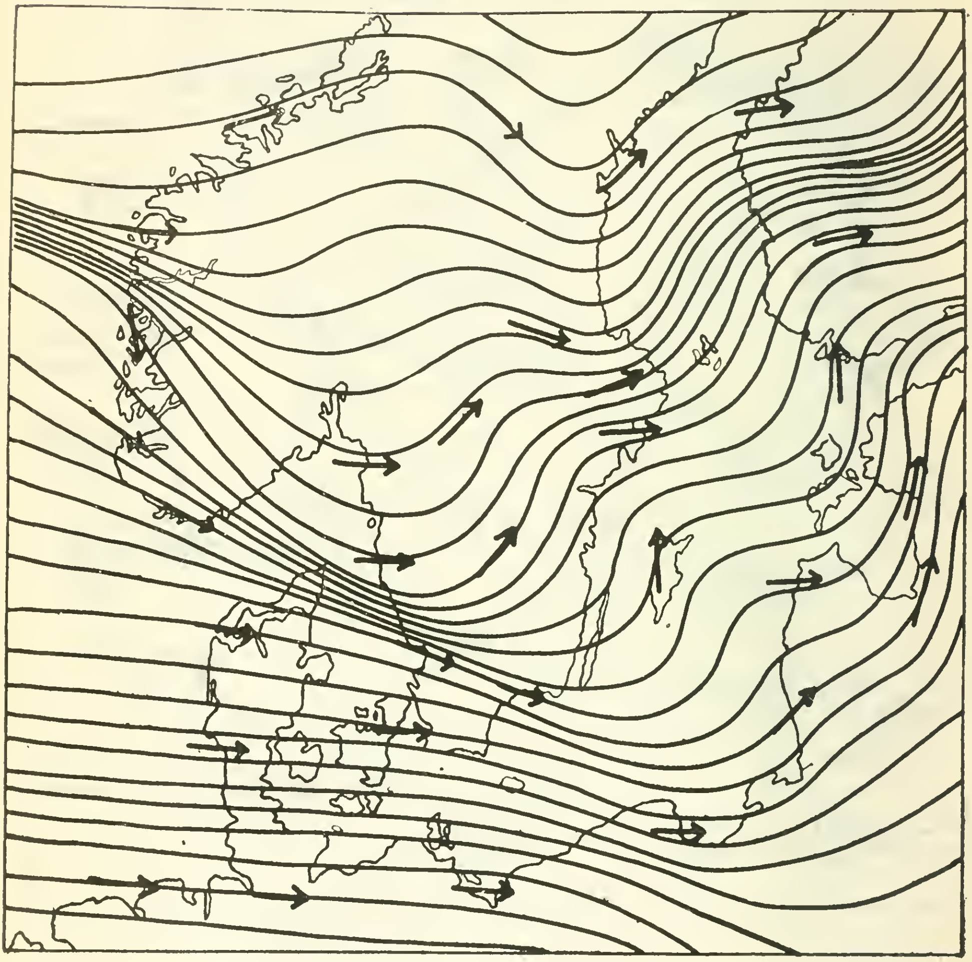


Fig. 59.—Courses of wind on 7 January, 1902, at 9 p.m.

will be dependent upon the phase of the oscillation. The variation in the depth of the isotherm gives this phase, and thus also furnishes a possibility of correcting for the same . It is an unsatisfactory matter of fact having frequently been noticed that hydrographical measurements repeated from the same station at a few hours' interval may give entirely different results, as well for velocity, temperature and salinity.

Obviously, these periodical oscillations are the exact opposite of stationary conditions, and the solenoids thus arising (*vide*, e.g., fig. 56) cannot therefore be used to calculate velocities according to formula (14). By so doing, entirely erroneous velocities would be obtained, with serious breaks to either side. Such breaks are, however an excellent indication of wave movements of this sort. The distribution of velocity in the boundary between the Labrador current and the Gulf Stream, *vide* plates XIV and XV, distinctly indicates that the sea is there in a state of violent oscillation.

Observations as to ebb and flow, and the currents occasioned thereby, should be treated according to the principles set forth in this chapter.

16. ON THE TOPOGRAPHY OF THE SEA'S SURFACE, THE DISTRIBUTION OF PRESSURE, AND TRANSFORMATION OF ENERGY IN THE SEA.

In order to illustrate further the enormous practical utility of Bjerknes' circulation theory in oceanographical work, I will here briefly touch upon one or two other examples.

Where a sea is in a state of perfect calm and equilibrium, all isobars and isosteres therein will coincide with the level surfaces of gravity. Such a state of equilibrium may be supposed to exist at great depths, so that the sea there would exhibit the same pressure at the same level. We can then, by means of the differential formula for measurement of barometric height,

$$dz = \frac{v\,dp}{g} \qquad (15)$$

which is equally applicable to the sea, arrive at the topography of the sea's surface. By integrating (15) from the surface down to the level of greatest pressure p_1, from which observations are available, we obtain

$$z = \frac{1}{g}\int_{p_0}^{p_1} v\,dp \qquad (16)$$

where z represents the height of the sea's surface above the isobaric surface p_1. If this calculation be carried out for several hydrographical verticals of measurement, we obtain the formation of the sea's surface $p=p_0$ relative to the isobaric surface $p=p_1$, i.e., the actual topography of the surface of the sea.

Owing to the great variation in the depths of the sea, the calculation may in practice best be carried out by reckoning the difference in height of the sea's surface at adjacent hydrographical stations, taken in pairs, and subsequently setting out all the results together in the form of a topographical map. According to (16), the difference in height between two hydrographical verticals will be as follows:—

$$z_1 - z_2 = \frac{1}{g}\int_{p_0}^{p_1} (v_1 - v_2)\,dp \qquad (17)$$

This integral operation is, however, identical with that carried out in tables 4 and 5. Using the terms there obtained, we get:

$$z_1 - z_2 = \frac{1}{g}\Sigma A \qquad (18)$$

i.e., we have here the data requisite for calculation of the topography of the sea's surface, by dividing the number of solenoids by the force of gravity.

Now table 5 contains values of Σ A not only for the surface of the sea, but also for isobars at deeper levels. The topography of these is then obtained in the same manner as that of the surface. We can thus, by the process here described, ascertain in the slope of the isobaric surfaces, and so arrive at the distribution of pressure throughout the entire portion of sea from which observations are available.

From the slope of the isobars, it is easy to ascertain the acceleration of the water. The most simple formulation of the relation between these two magnitudes is that given by Dr. J. Hann, viz., that the acceleration of the water is equal to that component for acceleration of gravity which falls in the isobar surface. Popularly speaking, we may say that the water slides down the sloping isobar surfaces, and that this sliding movement is practically frictionless.

This again, however, is as much as to say that the sea-water in such respect may be likened to the water of a river, and we can also apply the well-known laws for the flow of river water to the currents in the sea. As an example we may take the Gulf Stream. In this case,

$$\Sigma \text{ A} = 150000$$

On inserting this value in (18) we find that the surface of the sea lies about $1\frac{1}{2}$ metres higher in the Tropics than in the Arctic ocean. In other words, the Gulf Stream may be regarded as a great river, flowing down from a higher to a lower level.

The Gulf Stream carries 25,000,000 tons of water per second. This, with a fall of 1·5 metres, amounts to a force of 500,000,000 horse-power, which is the amount of energy expended in the propulsion of the Gulf Stream. It is utilized to overcome friction, and is thus converted into heat.

If we now insert ΣA=10880 in (18) we find that the surface of the sea during the summer of 1915 was 11·1 cm. higher at Station X 31 in the gulf of St. Lawrence than at station XIII 38 south of Nova Scotia. And as the Gaspé current carries 645,000 tons of water per second, its production of energy amounts to 955,000 horse-power, this force being utilized for its propulsion, and converted into heat by the internal friction of the water.

By thus directly comparing the ocean currents with rivers, we find it easier to comprehend the nature of the former, and the processes which take place therein. In a river, the slope of the river-bed occasions a continual transformation of potential energy into motive power. So also with ocean currents. In these, the slope of the sea's surface and of the isobars will represent a certain quantity of potential energy, which is gradually transformed into motive power, and thus maintains the movement of the current. And we have just seen, how the magnitude of this transformation of energy may be expressed in horse-power.

It is thus easy to follow the transformation of energy in the sea. The heat derived from the rays of the sun in the Tropics is first converted into potential energy, which again is then transformed into motive power, setting in motion currents which transport the warmer water to higher latitudes, where the heat is again given off from the sea. By periodical oscillations in the movement of the sea-water, the energy represented is continually being converted from potential force to motive power, and vice versa. The potential energy, however, after first being transformed into motive power, is thence again converted by the internal friction of the water into heat. We have thus the following system of transformation of energy in the sea:—

$$\text{HEAT} \longrightarrow \text{POTENTIAL ENERGY} \rightleftarrows \text{MOTIVE POWER} \longrightarrow \text{HEAT.}$$

This applies to all ocean currents. Thus the water in the St. Lawrence river, for instance, is due to the heating of the sea-water by the sun's rays, viz., firstly evaporation, then raining. The mixing of this fresh water with sea-water in the gulf of St. Lawrence gives rise to the potential energy which propels the Gaspé current. And finally, the motive power of this latter is transformed, by the internal friction of the

water, into heat. In the case of the Gaspé current, the measure of these three transformations of energy will be 955,000 horse-power.

The divergence of the sea's surface from the level of gravity is primarily due to such physical changes in the sea-water as bring about an alteration of its specific gravity. The topography of the sea's surface is, however, further influenced by the earth's rotation, which forces the light surface water of the currents to the right; and also by the wind, which forces the water to store up. In addition, the surface of the sea is subjected to various periodical perturbations, taking the form of sea waves, seiches, swells, etc. In all such obliquities of the sea's surface, however, the water will always be accelerated by the component which falls in the surface of the sea, if the force of gravity is projected upon the same.

One deformation of the sea's surface should be reckoned in a class apart, viz., that due to atmospheric pressure. If, for instance, the pressure above a certain area of sea should fall from, say, 760 to 720 mm., then according to (15) the pressure will be correspondingly reduced, and this, moreover, right down to the bottom of the sea; *i.e.*, all isobar surfaces within the area in question, down to the greatest depth, will be lowered 34 cm. The result of this will be an inflow of water from all sides to the area in question, this taking place rapidly, and with imperceptible velocity, as all levels of the water contribute. When this process has been completed, the surface of the sea within the area of lowered atmospheric pressure will have risen 54 cm. above its former level, this height of the water exactly compensating the deficit in atmospheric pressure, so that the isobars will then resume their normal course, despite the atmospheric perturbation. The surface of the sea itself, however, will no longer be an isobar surface, and ceases therefore, to be an indication of the distribution of pressure in the sea. This it can only become through a combination of water level and atmospheric pressure.

It is therefore a question, whether it might not be worth while, for dynamic purposes to carry out this combination. The simplest method of so doing is to correct the water level to a certain pressure, *e.g.* 1,000000′CGS, corresponding to 750·08 mm. or 29·531 inches Hg. at O°. This pressure will always be found near the surface of the sea. Insertinging now in (15) $g=980 \cdot 6$ and $v=0 \cdot 97264$, we obtain the required correction of the water level for the influence of atmospheric pressure:—

$$z = \frac{0 \cdot 97264}{980 \cdot 6} \quad (p - 1000000)$$

or

$$z=0 \cdot 0009919 \ (p - 1000000)$$

Taking now as unit of pressure 1 millibar = 1,000 C.G.S., then

$$z=09919 \ (p - 1000) \qquad (19)$$

In mm. Hg.

$$z=1 \cdot 3224 \ (p - 750 \cdot 08) \qquad (20)$$

and in inches Hg.

$$z=33 \cdot 59 \ (p - 29 \cdot 531) \qquad (21)$$

Table 7, a, b, and c, gives the correction z to the water level expressed in cm. for different atmospheric pressures according to formulæ (19), (20), and (21), respectively.

By applying this correction to the water levels observed, we obtain the water level which determines the distribution of pressure in the sea and the movement of the water.

Finally, as regards transformation of energy in the sea, it should be borne in mind that the integral expression in formula (17) gives the area of the closed curve in Clapeyron's diagram. In the case of a current where the water flows in a Carnot circular process, as for instance the Gulf Stream, the quantity of energy converted from heat to motive power will thus be equal to the mass of water in circulation, multiplied by the number of solenoids. This calculation gives, for the Gulf Stream,

500,000,000 horse-power, which agrees with the value already known from other methods of calculation.

Nothing could show more clearly than this the fundamental importance of the solenoids for the origin and maintenance of the ocean currents.

17. SUMMARY.

Within the area of these investigations, from its boundary on the Gulf Stream side to the mouth of the St. Lawrence, a number of mostly interesting phenomena are encountered, which render the waters in question one of the most instructive fields on the face of the globe for hydrographical and hydrodynamic research.

Let us now glance briefly at some of the most important features. First of all, there are the physical processes which take place in the boundary surface between the Labrador current and the Gulf Stream occasioning the disappearance of the former, with regard to these, the reader is referred to Prof. Emil Witte's clear and simple treatment of the subject in the *Geogr. Anzeiger,* October, 1910:—

> " When, on the boundary of an ocean current, warm water of high salinity is brought into contact with colder water of less saline character, but having approximately the same specific gravity, then the resulting mixture will, as may easily be proved by the Knudsen tables, be of greater density than either of its component parts. It will consequently sink down, giving rise to the peculiar phenomenon known as cabbeling.
>
> " Obviously, this tendency in the water will likewise produce horizontal currents; as the mixed water sinks down, surface water must flow in from either side to take its place. By way of example, we may take the waters in the vicinity of the Newfoundland bank, where the Gulf Stream encounters the cold current flowing down from the Greenland seas. Throughout the wide extent of the boundary surface between these two, mixed water is constantly being formed, sinking down, and thus drawing in a continual further supply of surface water from either side."

It is this perpetual sinking of the water, of course, which renders the oceanic boundary line here so vertical.

Numerous pelagic organisms of slight mobility doubtless meet their death in this mixture of the water, and their shells sink to the bottom. With the aid of boring samples taken from the sea floor, therefore, we should probably be able to arrive at the geological history of these currents.

The water of the Gulf Stream is more homogeneous; that of the Labrador current being more in layers. In the boundary surfaces between the layers of the latter, wave movements take place. These waves strike against the vertical boundary wall, giving rise to submarine waves of great amplitude. In order to study these, it will be sufficient to measure the depth of an isotherm or isohaline at the juncture of two layers. This simple operation should be carried out at the same time as the hydrographical measurements.

Closer in towards land, the surface water of the Labrador current is driven by the earth's rotation in a shoreward direction, which is one of the causes of the numerous shipwrecks in the Newfoundland waters. The water pours up into the big bays on the eastern shore, keeping to their north side. The greater part of the water thus poured in at the surface makes its way out again as an under current, but there is, as a rule, also a slight surface current in an outward direction on the southern side of the bays.

South of Newfoundland, the landward current is often perceptible far out at sea. " A northerly set of 30 miles in twenty-four hours has frequently been experienced in this neighbourhood, at times at a distance of 50 miles from the coast (*vide* Sailing

Directions from Belle Isle to Boston). In the bays of the south coast of Newfoundland, the water flows in up their eastern side, and out along the bottom, with an outward-going surface current also on the western side.

From the foregoing, it will be plain that the majority of the icebergs drifting with the Labrador current will collect on its western side, making their way up into the bays on the east and south coasts of Newfoundland as far as Placentia bay. The suction towards the boundary between the Labrador current and the Gulf Stream will, however, draw a number of icebergs thither; they may be encountered far out at sea and to the southward, even occurring down towards the east and south sides of the Great Bank. In the intermediate zone, between the two ice lines, the current should be relatively free from ice.

At cape Ray, the water of the Labrador current pours into the gulf of St. Lawrence at the rate of some 12 cubic miles per day. Its place of destination is here the consumption area at the mouth of the St. Lawrence river, where this quantity of water is required for the production of the Gaspé current. We have thus in the gulf of St. Lawrence a solenoid system drawing this water towards the northwest. At cape Ray, however, where the velocity of the water becomes considerable, owing to the narrow passage through which it flows, the influence of the earth's rotation also makes itself strongly felt. The current, therefore, on entering the bay, veers off to the right in a curve, this curve being, however, of wide radius, owing to the pressure exerted by the solenoids in a northwesterly direction. It consequently passes by the bay of St. George without entering there, touching the west coast of Newfoundland for the first time at the bay of Islands, and setting on shore from there as far as point Rich.

On the way it loses a great deal of water which sets off westward out into the gulf of St. Lawrence, making for its destination, the mouth of the St. Lawrence river. The last remainder of the current also curves out from point Rich into the gulf, following the attraction of the solenoids. A slight westward current is still perceptible along the north coast of the bay, from Esquimaux island to cape Whittle. Morgan strait being shallower than the level of the solenoid system which draws the water westward, the current leaves the coast at cape Whittle, passing out east and south of Anticosti to reach its destination. In the region north of Anticosti, a slight back vortex seems to arise, as the current is directed eastward along the range of coast beyond Natashquan point.

South and west of Anticosti, the earth's rotation forces the current over to the northward. The effect, however, is insignificant, owing to the great extent of the current in transverse section, and its consequent slight velocity.

At the mouth of the St. Lawrence river, we encounter the mixing process which gives rise to the Gaspé current. In all probability, the ebb and flow of the tide are, for this process, of considerable importance.

In this mixed water of the Gaspé current, the fresh water from the St. Lawrence constitutes a quantitatively insignificant yet highly important ingredient; it is this which renders the Gaspé water slightly lighter than the surrounding sea-water, which again gives rise to the solenoid system that forces the Gaspé water out of the gulf of St. Lawrence, and draws in the Labrador water. Owing to the earth's rotation, the Gaspé current keeps to the southern side of the entrance to the St. Lawrence, rounding cape Gaspé, and filling the southern part of the gulf. Here the Gaspé water accumulates, forming a kind of cushion, and the Gaspé current itself flows thereafter on the north side of the same. As a rule, the current flows south of the Magdalen islands, but when the "cushion" is well developed, part of the current may go north of this group. Within the cushion itself reactionary currents arise, especially in the vicinity of the primary Gaspé current, and where the cushion is very strongly developed, such a reactionary current may even extend up as far as cape Gaspé, pressing the Gaspé current even here out from land.

Gradually, owing to rainfall, inflow of river water, melting of ice, etc., the water of the cushion becomes somewhat lighter than that of the Gaspé current, and is thus better able to resist the southward pressure of the current itself.

In Cabot strait, the continuation of the Gaspé current keeps close in to cape North, C. Breton island, owing to the earth's rotation. With a strong easterly wind, the whole of this current will be stopped, and all its water stored up in the cushion in the southern part of the gulf of St. Lawrence. The cushion is thereby increased both in depth and horizontal extent, and consequently, the solenoids in the gulf of St. Lawrence, which drive the Gaspé water forward, become stronger in turn. If the east wind keeps up for any length of time, this solenoid system will at last become so strong as to drive the Gaspé water past cape North, despite the wind against it. When the east wind drops, the current will be stronger than normal for a time, as it will then, in addition to the Gaspé water, also have to carry out the superfluous water of the cushion.

With a southwesterly wind, on the other hand, the water of the cushion will be driven out through Cabot strait. The current is thus increased at first, but when the water in the cushion has sufficiently diminished the current past cape North will once more become normal, despite the southwesterly wind. When the southwesterly wind ceases, the current will grow weaker, as a great part of the Gaspé water will then go to form a new cushion. In a word, the effect of this accumulated mass of water may be popularly described as similar to that of the air in the bag of a Scottish bagpipe.

The principal portion of the Gaspé water is naturally formed outside the mouth of the St. Lawrence river, but the current also absorbs a considerable amount of water from its surroundings throughout its course, by friction against the subjacent layer, and by diffusion. Consequently, the farther it proceeds, the more it increases in volume and salinity and the more it grows to resemble the water around it. On the coast of Nova Scotia, and even more in the gulf of Maine, it differs but slightly from its surroundings, and a storm will here suffice to mix it up completely with the adjacent water. Thus far at least, however, the water of the St. Lawrence river flows before losing its individuality and becoming finally intermingled with the ocean.

We now come to the most remarkable feature in the hydrography and hydrodynamics of the Canadian Atlantic area, viz., the cold intermediate layer. From plates IV and V it will be seen that this is of very great extent, and that it is largely restricted to a constant level. It is a result of the melting of ice in the gulf of St. Lawrence, and partly, also in all probability, in the Arctic ocean. From the section east of cape Ray, it would seem that this layer forms an important intermediate or lower portion of the Labrador current. Its movement, together with this latter, is unmistakable. The cold water presses against the banks and the coast, as a result of the earth's rotation, which forces it towards the right.

It is thus likely that the greater portion of this water is produced farther to the north, in the Greenland waters. Its thickness decreasing to the southward, we consequently find, in the cold layer itself, solenoids which force it towards this point of the compass. On reaching Cabot strait, it is forced by the earth's rotation into the gulf of St. Lawrence, and fills it to the level where it belongs by virtue of its specific gravity. From the gulf of St. Lawrence it pours out via cape North along the coast of Nova Scotia or rounding Banquereau. These outward currents are considerably stronger in spring than in summer, owing to the melting of the ice in the gulf during the former season. A peculiar phenomenon may be noted in connection with these. The screwing movement of the ocean current presses the cold subjacent water out from the shore, *vide* plates IV and V, where, owing to friction against the water above, it probably rotates in an opposite direction to the latter, exactly as two cogwheels in contact move opposite ways. In this manner, the cold water mass acquires its rounded form, as shown in fig. 60.

The layer of cold water is thinner in the centre of the gulf of St. Lawrence than at peripheral parts of the same; the layer is thus in cyclonic circulation.

The extent and permanence of the cold water layer show that no interchange of

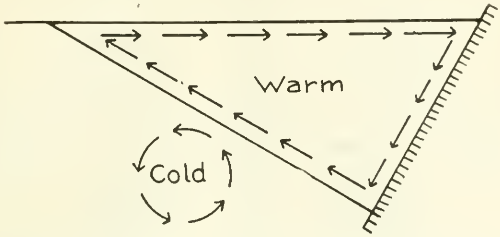


Fig. 60.—Circulation of the water in a transverse section of a current with cold bottom water.

water can take place between the surface and bottom layers in the gulf of St. Lawrence. The cold layer forms an elastic but impenetrable membrane between the surface water and the bottom water. Its level is dependent upon the state of the Labrador current, and thus probably determined by the seasons; also accidental causes may, however, have some effect. With an easterly wind, when great quantities of surface water will be pressed in and corresponding masses of bottom water forced out through Cabot strait, the level of the cold layer will sink in the gulf, and rise outside it. With a westerly wind, on the other hand, when the surface water is driven out and the bottom water sucked in through Cabot strait, then the level of the cold layer is raised inside the gulf and lowered outside. Enormous slow wave movements also probably take place within the layer. As its level approximately corresponds with that of the Banks, its change of level will obviously occasion marked changes of temperature there. These changes of temperature, moreover, probably affect the occurrence of fish on the banks, as the fish may be presumed to seek that water they best like. In seeking to locate the fish, therefore, it will undoubtedly be valuable to know at what level this cold water is to be found.

The warm bottom layer in the gulf of St. Lawrence is connected with the outer world only by the long, deep channel of the Cabot strait. No production or consumption of this water takes place in the gulf of St. Lawrence, and its movements there are consequently insignificant. In the deep channel through the Cabot strait, however, this water may at times exhibit no inconsiderable degree of movement. Measurements of this deep-water current would be of great dynamic importance, possibly also important in biological respects, since they would show whether the cold layer were rising or falling, i.e., in what direction the hydrographic condition of the gulf of St. Lawrence is tending. The deep water of the gulf of St. Lawrence may be considered as an elastic membrane exhibiting a number of important hydrographical phenomena, all of which exert their influence upon it. The current flowing inward and outward through the deep channel of Cabot strait indicates the measure of this influence, and thus affords a valuable means of discerning what is taking place in the gulf of St. Lawrence.

TABLE 1*a*.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the spring 1915.

C. G. S. "PRINCESS".

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 1 May 11	0	663	0
N. 47° 30′ 00″	10	663	47
W. 63° 23′ 00″	20	616	16
69 m.	30	600	46
	40	554	6
	50	548	4
	65	542	
Stat. 2 May 11	0	671	0
N. 47° 27′ 00″	10	671	20
W. 62° 10′ 30″	20	651	28
45 m.	30	623	68
	40	555	
Stat. 3 June 9	0	930	134
N. 46° 02′	10	796	19
W. 63° 25′	20	777	30
25 m.	22	771	
Stat. 4 June 9	0	899	18
N. 46° 28′	5	890	28
W. 64° 21′	10	876	32
21 m.	20	844	
Sect. I, 5. June10	0	935	58
N. 47° 13′	10	877	135
W. 64° 35′	20	742	107
31 m.	30	635	
Sect. I, 6. June 10	0	909	221
N. 47° 30′	10	688	58
W. 64° 08′	20	630	72
61 m.	30	558	1
	40	557	16
	60	525	
Sect. I, 7. June 10	0	934	89
N. 47° 50′	10	845	169
W. 63° 37′	25	592	12
76 m.	50	562	19
	75	514	
Sect. I, 8. June 10	0	802	62
N. 48° 11′	10	740	147
W. 63° 04′	20	593	20
92 m.	40	553	24
	60	506	12
	90	469	
Sect. I, 9. June 11	0	642	37
N. 48° 27′	25	550	16
W. 62° 37′	75	471	17
160—300 m.	100	428	9
	150	382	
Sect. I, 10. June 11	0	631	35
N. 48° 53′	25	538	14
W. 61° 50′	50	503	20
150—250 m.	75	452	10
	100	427	6
	150	395	5
	200	370	
Sect. I, 11. June 11	0	617	6
N. 49° 02′	10	611	39
W. 61° 32′	20	572	39
51 m.	25	513	3
	40	508	19
	50	489	

TABLE 1*a*.—Specific volume v_1, and stability S of the water in the Gulf of St. Lawrence during the spring 1915—*Continued.*

G. C. S. "PRINCESS"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. I, 12. June 11	0	630	65
N. 49° 27′ W. 61° 20′	10	565	26
140 m.	25	526	12
	50	495	19
	75	448	8
	100	427	2
	125	421	
Sect. I, 13. June 11	0	819	103
N. 49° 45′ W. 61° 15′	25	561	27
ca. 200 m.	50	493	18
	75	449	3
	100	441	11
	125	414	2
	150	408	5
	200	384	
Sect. I, II, 14. June 11	0	996	311
N. 50° 07′ W. 61° 09′	10	685	150
40 m.	20	535	26
	35	496	
Sect. II, 15. June 12	0	769	7
N. 49° 45′ W. 60° 08′	10	762	126
85 m.	20	636	77
	40	483	14
	60	455	17
	80	422	
Sect. II, 16. June 12	0	580	12
N. 49° 33′ W. 59° 31′	25	550	21
260 m.	50	497	23
	75	440	8
	100	420	5
	150	394	0
	200	392	6
	250	364	

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. II, 17. June 12	0	564	8
N. 49° 22′ W. 58° 56′	25	544	16
130 m.	50	505	20
	75	456	6
	100	449	10
	125	415	
Sect. II, 18. June 12	0	590	26
N. 49° 16′ W. 58° 37′	30	513	22
64 m.	40	481	8
	50	473	
Sect. III, 19. June 13	0	563	10
N. 48° 20′ W. 59° 13′	10	553	1
82 m.	20	552	41
	30	511	11
	50	490	31
	60	458	7
	80	445	
Sect. III, 20. June 13	25	556	7
N. 48° 06′ W. 59° 40′	50	538	22
250—400 m.	75	482	12
	100	451	10
	125	427	7
	150	409	8
	200	371	
Sect. III, 21. June 13	0	543	0
N. 47° 52′ W. 60° 04′	25	542	17
ca. 500 m.	50	499	13
	75	466	10
	100	442	9
	200	355	1
	300	341	3
	400	314	

TABLE 1*a*.—Specific volume v_1 and stability *S* of the water in the Gulf of St. Lawrence during the spring 1915—*Continued.*

C. G. S. "PRINCESS"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. III, 22. June 13	10	565	
N. 47° 33′			15
W. 60° 39′	20	550	
55 m.			49
	30	501	
			1
	40	500	
			5
	50	495	
Sect. III, 23. June 13	20	555	
N. 47° 37′			25
W. 60° 31′	40	505	
ca. 100 m.			48
	45	481	
			7
	55	474	
			28
	60	460	
			7
	80	446	
			16
	100	414	
Sect. III, 24. June 15	0	607	
N. 47° 12′			2
W. 61° 20′	10	665	
40 m.			27
	25	624	
			56
	35	568	
Sect. III, 25. June 15	0	746	
N. 46° 45′			7
W. 61° 27′	10	739	
63 m.			145
	20	594	
			47
	30	547	
			6
	40	541	
			4
	60	533	
Sect. III, 26. June 15	0	782	
N. 46° 20′			17
W. 62° 04′	10	771	
40 m.			53
	20	712	
			58
	25	683	
			90
	35	593	

STEAM DRIFTER "33".

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. IV, 21. June 25	0	805	
N. 48° 51′			163
W. 64° 10′	10	642	
27 m.			62
	24	555	
Sect. IV, 22. June 25	0	826	
N. 48° 54′			95
W. 64° 07′	10	731	
195 m.			145
	20	586	
			47
	30	539	
			24
	50	492	
			11
	75	464	
			20
	100	415	
			14
	125	388	
			2
	150	375	
			2
	190	368	
Sect. IV, 23. June 25	0	823	
N. 49° 03′			27
W. 63° 58′	10	796	
355 m.			188
	20	608	
			51
	30	557	
			3
	50	497	
			18
	75	452	
			10
	100	428	
			8
	150	388	
			7
	250	351	
			2
	350	328	
Sect. IV, 24. June 26	0	641	
N. 49° 23′			32
W. 63° 38′	10	609	
45 m.			16
	24	587	
			66
	42	469	

TABLE 1*a*.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the spring 1915—*Concluded*.

STEAM DRIFTER "33"—*Concluded*.

Station, time, position, depth.	Depth m.	v_1.	S.	Station, time, position, depth.	Depth m.	v_1.	S.
Sect. IV, 25. June 26	0	744		Sect. IV, 26. June 26	0	825	
			4				42
N. 49° 18′ 30″	10	740		N. 49° 11′ 30″	10	783	
W. 63° 42′ 00″			38	W. 63° 50′ 00″			101
	20	702			20	682	
271 m.			151	389 m.			149
	30	551			30	533	
			26				36
	50	499			50	462	
			18				9
	75	455			75	440	
			15				7
	100	418			100	422	
			5				6
	150	393			150	394	
			5				7
	269	335			200	358	
							2
					250	347	
							2
					380	321	

TABLE 1*b*.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915.

C. G. S. "ACADIA".

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. V, 1. May 29	10	611	
N. 44° 35′ 00″ W. 63° 32′ 00″			57
25 m.	20	554	
Sect. V, 2. May 29	0	603	
N. 44° 29′ 00″ W. 63° 22′ 00″			0
60 m.	10	603	
			4
	20	599	
			28
	30	571	
			29
	40	542	
			16
	55	518	
Sect. V, 3. May 29	0	606	
N. 44° 22′ 30″ W. 62° 55′ 00″			2
146 m.	10	604	
			12
	20	592	
			63
	30	529	
			31
	40	498	
			12
	50	486	
			3
	60	483	
			7
	75	472	
			12
	90	454	
			5
	110	445	
Sect. V, 4. May 29	0	564	
N. 44° 07′ 14″ W. 62° 11′ 36″			0
173 m.	10	564	
			6
	25	555	
			21
	40	524	
			21
	50	503	
			29
	60	474	
			12
	100	425	
			10
	120	406	
			7
	160	379	
Sect. V, 5. May 30	0	505	
N. 43° 56′ 00″ W. 61° 32′ 00″			7
73 m.	10	498	
			11
	25	408	
			8
	50	460	
			12
	70	437	
Sect. V, 6. May 30	0	519	
N. 43° 47′ 00″ W. 60° 52′ 00″			0
45 m.	10	519	
			0
	20	519	
			2
	30	517	
			9
	40	508	
Sect. V, 7. May 30	0	528	
N. 43° 35′ 30″ W. 60° 13′ 30″			6
109 m.	25	514	
			34
	50	429	
			0
	75	429	
			17
	100	387	
Sect. V, 8. May 30	0	539	
N. 43° 50′ 30″ W. 60° 04′ 30″			1
51 m.	10	538	
			14
	20	524	
			14
	30	510	
			1
	40	509	
			80
	50	501	
Sect. V, 9. May 30	25	501	
N. 43° 44′ 00″ W. 59° 24′ 00″			43
106 m.	40	437	
			16
	50	421	
			0
	75	421	
			8
	100	401	

TABLE 1*b*.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.		Depth m.	v_1.	S.
Sect. V, 10.	May 30	0	488	
				4
N. 43° 41′ 30″ W. 59° 02′ 00″		25	476	
				10
740 m.		50	451	
				10
		60	441	
				6
		75	432	
				26
		90	393	
				5
		100	388	
				6
		150	360	
				2
		300	332	
				1
		400	318	
Sect. V, 11.	May 30	25	471	
				6
N. 43° 38′ 00″ W. 58° 35′ 00″		50	455	
				23
over 500 m.		75	398	
				8
		100	378	
				5
		125	366	
				7
		150	348	
				1
		300	338	
				1
		400	328	
Sect. V, 12.	May 31	0	479	
				2
N. 43° 31′ 00″ W. 57° 46′ 00″		10	477	
				31
over 500 m.		25	431	
				2
		50	427	
				4
		75	418	
				4
		100	408	
				3
		125	400	
				9
		150	377	
				5
		175	364	
				2
		300	345	
				1
		400	333	
Sect. V, 13.	May 31	0	508	
				20
N. 43° 27′ 35″ W. 27° 18′ 25″		25	459	
				23
over 500 m.		50	402	
				6
		75	387	
				8
		100	366	
				4
		150	347	
				2
		200	337	
Sect. V, 14.	May 31	0	451	
				3
N. 43° 20′ 00″ W. 56 28′ 30″		25	443	
				5
over 500 m.		50	430	
				0
		75	430	
				61
		85	369	
				2
		100	366	
				5
		125	353	
				2
		150	348	
				1
		300	327	
				1
		400	321	
Sect. V, 15.	May 31	0	472	
				1
N. 43 07′ 50″ W. 55 17′ 55″		25	470	
				15
over 500 m.		50	433	
				0
		75	432	
				18
		100	388	
				5
		150	362	
				2
		300	337	
				1
		400	326	

TABLE 1b.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. V, VI, 16. June 1	0	411	
			1
N. 42° 53′ 00″ W. 54° 09′ 00″	25	409	
			2
	75	399	
over 500 m.			3
	100	391	
			2
	200	375	
			1
	300	362	
			2
	400	346	
Sect. VI, 17. June 1	25	405	
			3
N. 43° 13′ 50″ W. 54° 12′ 50″	50	397	
			0
over 500 m.	100	395	
			3
	150	379	
			1
	300	364	
			1
	400	352	
Sect. VI, 17a. June 1	0	436	
			7
N. 43° 56′ 00″ W. 54° 16′ 00″	75	383	
			1
over 500 m.	100	380	
Sect. VI, 18. June 1	0	460	
			2
N. 44° 11′ 30″ W. 54° 13′ 00″	25	455	
			4
	50	446	
over 500 m.			20
	75	396	
			5
	100	383	
			4
	150	362	
			2
	300	327	
			1
	400	317	
Sect. VI, 19. June 1	0	462	
			0
N. 44° 35′ 00″ W. 54° 15′ 00″	25	462	
			3
	50	454	
over 500 m.			31
	75	377	
			0
	100	376	
			2
	150	366	
			2
	300	340	
			0
	400	339	

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. VI, 20. June 2	0	463	
			1
N. 44° 59′ 00″ W. 54° 17′ 00″	25	460	
			6
	50	445	
91 m.			12
	75	416	
Sect. VI, 21. June 2	0	453	
			6
N. 45° 28′ 00″ W. 54° 28′ 00″	35	433	
			1
	50	432	
116 m.			15
	65	409	
			4
	100	394	
Sect. VI, VII, 22. June 2	0	460	
			3
N. 45° 50 ′30″ W. 54° 20 ′00″	20	455	
			8
	40	445	
73 m.			20
	50	425	
			14
	60	411	
Sect. VII, 23. June 2	0	459	
			1
N. 45° 39′ 00″ W. 55° 03′ 00″	25	456	
			8
	50	435	
100 m.			14
	60	421	
			0
	75	421	
Sect. VII, 24. June 2	0	465	
			6
N. 45° 16′ 30″ W. 59° 29′ 50″	50	436	
			8
	75	416	
120 m.			0
	100	415	
Sect. VII, 25. June 2	0	457	
			5
N. 44° 56′ 00″ W. 55° 54′ 00″	25	445	
			11
124 m.	50	418	
			3
	100	404	
			7
	120	391	

TABLE 1b.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_8.	S.
Sect. VII, 26. June 2	0	507	
			14
N. 44° 31′ 00″ W. 56° 25′ 30″	25	473	
			6
	50	457	
over 500 m.			13
	100	391	
			11
	125	363	
			7
	150	346	
			16
	300	322	
			1
	400	313	
Sect. VII, VIII, 27. June 3	25	464	
			10
N. 44° 06′ 00″ W. 56° 54′ 00″	50	438	
			13
	75	406	
over 500 m.			10
	100	386 } 376	
			2
	150	369	
			3
	300	327	
			1
	400	315	
Sect. VIII, 28. June 3	0	542	
			12
N. 44° 12′ 00″ W. 57° 24′ 00″	25	513	
			7
	50	495	
over 500 m.			18
	75	450	
			11
	100	423	
			10
	150	373	
			2
	300	340	
			3
	400	314	
Sect. VIII, 29. June 3	0	550	
			7
N. 44° 21′ 36″ W. 58° 08′ 00″	40	522	
			32
	55	475	
58 m.			

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. VIII, 30. June 3	0	563	
			8
N. 44° 40′ 50″ W. 58° 42′ 00″	25	542	
			21
	50	490	
127 m.			1
	75	487	
			6
	100	472	
			7
	125	454	
Sect. VIII, 31. June 3	0	584	
			8
N. 45° 13′ 00″ W. 58° 59′ 00″	25	563	
			28
	50	493	
85 m.			5
	75	481	
Sect. VIII, 32. June 3	0	572	
			16
N. 45° 48′ 30″ W. 59° 13′ 00″	25	532	
			6
	50	517	
155 m.			12
	100	455	
			7
	150	419	
Sect. VIII, IX, 33. June 4	0	630	
			4
N. 46° 16′ 30″ W. 59° 33′ 00″	15	624	
			53
	25	571	
ca. 73 m.			26
	40	532	
			16
	50	516	
			18
	75	470	
Sect. IX, 34. June 4	0	522	
			10
N. 46° 40′ 00″ W. 59° 00′ 00″	25	498	
			12
	50	469	
ca. 350 m.			3
	100	453	
			6
	200	394	
			6
	300	339	

TABLE 1*b*.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Concluded.*

C. G. S. "ACADIA"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	S.	Station, time, position, depth.	Depth m.	v_1.	S.
Sect. IX, 35. June 4	0	514		Sect. IX, 36. June 4	0	521	
			5				12
N. 47° 04′ 00″ W. 58° 26′ 00″	15	507		N. 47° 26′ 00″ W. 57° 57′ 00″	25	492	
			10				14
	30	492			50	458	
			13				5
ca. 450 m.	50	462		230 m.	75	445	
			12				5
	75	431			150	406	
			6				7
	100	417			200	369	
			7				
	150	380					
			3				
	300	329					
			1				
	400	321					

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915.

C. G. S. "PRINCESS"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 27. Aug. 3	0	1019	22
N. 46° 02″ W. 63° 24′	10	997	253
23 m.	20	744	
Stat. 28. Aug. 3	0	1082	38
N. 46° 31′ W. 64° 20′	10	1044	12
23 m.	20	1032	
Sect. X, 29. Aug. 4	0	1122	90
N. 47° 13′ W. 64° 36′	10	1032	294
32 m.	15	885	140
	20	815	60
	25	785	
Sect. X, 30. Aug. 4	0	1013	6
N. 47° 31′ W. 64° 09′	10	1007	105
66 m.	25	850	65
	40	753	94
	50	659	136
	60	523	
Sect. X, 31. Aug. 4	0	1068	68
N. 47° 47′ W. 63° 45′	10	1000	144
65 m.	25	784	78
	40	667	132
	50	535	38
	60	497	
Sect. X, 32. Aug. 4	0	982	208
N. 48° 00′ W. 63° 25′	10	774	111
87 m.	25	607	37
	50	514	10
	75	489	7
	85	482	
Sect. X, 33. Aug. 4	0	954	202
N. 48° 17′ W. 62° 54′	10	752	123
78 m.	25	567	32
	50	487	20
	75	438	
Sect. X, 34. Aug. 4	0	828	122
N. 48° 27′ W. 62° 37′	10	706	53
405 m.	25	626	55
	50	488	13
	75	454	12
	100	424	8
	150	383	4
	200	363	3
	300	329	2
	350	321	
Sect. X, 35. Aug. 5	0	775	19
N. 48° 41′ W. 62° 15′	10	756	125
ca. 400 m.	25	568	39
	50	471	9
	75	449	8
	100	428	6
	150	396	6
	200	367	4
	300	331	1
	350	326	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Continued.*

C. G. S. "PRINCESS"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. X, 36. Aug. 5	0	827	1
N. 48° 58′	10	826	106
W. 61° 48′	25	667	144
53 m.	35	523	17
	50	497	
Sect. X, 37. Aug. 5	0	785	11
N. 49° 06′	10	774	150
W. 61° 21′	25	549	30
75 m.	50	474	16
	70	443	
Sect. X, 38. Aug. 5	0	816	19
N. 49° 28′	10	797	183
W. 61° 22′	25	523	24
180 m.	50	462	11
	75	434	7
	100	417	5
	150	392	0
	175	392	
Sect. X, 39. Aug. 5	0	801	11
N. 49° 45′	10	790	175
W. 61° 19′	25	527	26
284 m.	50	462	10
	75	437	8
	100	417	3
	150	400	3
	200	385	6
	275	338	
Sect. X, XI, 40. Aug. 5	0	848	233
N. 50° 05′	10	615	62
W. 61° 16′	25	522	24
68 m.	40	486	17
	50	469	0
	65	468	
Sect. XI, 41. Aug. 6	0	776	1
N. 49° 54′	10	775	119
W. 60° 37′	25	597	37
189 m.	50	504	20
	75	455	10
	100	431	8
	150	411	9
	180	385	
Sect. XI, 42. Aug. 6	0	749	1
N. 49° 45′	10	748	89
W. 60° 07′	25	615	48
90 m.	50	496	24
	75	437	1
	85	436	
Sect. XI, 43. Aug. 6	0	749	1
N. 49° 33′	10	748	98
W. 59° 28′	25	601	42
265 m.	50	496	20
	75	445	20
	100	427	5
	150	402	5
	200	374	6
	250	346	

Table 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Continued.*

C. G. S. "PRINCESS"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XI, 44. Aug. 6	0	753	2
N. 49° 24′ W. 58° 55′	10	751	108
157 m.	25	589	42
	50	485	14
	75	451	8
	100	430	6
	150	401	
Sect. XII, 45. Aug. 12	0	660	14
N. 47° 53′ W. 59° 38′	25	624	44
380 m.	50	513	18
	75	467	5
	100	454	4
	150	436	8
	200	398	9
	300	313	0
	375	310	
Sect. XII, 46. Aug. 12	0	690	36
N. 47° 41′ W. 59° 52′	25	600	49
ca. 455 m.	50	477	9
	75	454	6
	100	438	8
	150	399	7
	200	365	3
	300	332	1
	400	320	
Sect. XII, 47. Aug. 12	0	833	55
N. 47° 25′ W. 60° 10′.	25	696	58
410 m.	50	552	28
	75	481	12
	100	451	10
	150	402	5
	200	378	4
	300	342	2
	400	321	
Sect. XII, 48. Aug. 12	0	878	99
N. 47° 08′ W. 60° 31′	25	631	53
175 m.	50	498	21
	75	446	8
	100	427	18
	125	383	4
	170	364	
Sect. XII, 49. Aug. 12	0	990	30
N. 46° 40′ W. 61° 14′	10	960	206
75 m.	25	651	116
	35	535	8
	50	523	19
	60	504	37
	70	467	
Sect. XII, 50. Aug. 12	0	959	2
N. 46° 18′ W. 61° 59′	10	957	97
42 m.	25	811	150
	40	586	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Concluded.*

STEAM DRIFTER "33".

Station, time. position, depth.	Depth m.	v_1.	S.
Stat. 54. Aug. 7	0	1393	679
South Arm,	10	714	105
Bay of Island, Newfoundland.	25	557	15
110 m.	50	519	18
	75	473	3
	100	465	
Stat. 58. Aug. 10	0	784	72
Off South Head,	10	712	99
Bay of Island.	25	564	32
50 m.	45	501	
Stat. 59. Aug. 10	0	790	88
Inside South Head,	10	702	101
Bay of Island.	25	551	25
275 m.	50	488	6
	75	472	5
	100	460	3
	150	446	0
	200	444	0
	270	442	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915.

C. G. S. "ACADIA."

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XIII, 37. July 21	0	653	
N. 43° 33′ 00″			37
W. 65° 12′ 50″	20	579	
62 m.			27
	40	525	
			8
	60	509	
Sect. XIII, 38. July 21	0	709	
N. 43° 14′ 00″			32
W. 65° 02′ 00″	25	630	
170 m.			29
	50	558	
			23
	75	501	
			19
	100	453	
			5
	125	440	
			5
	150	427	
Sect. XIII, 39. July 21	0	693	
N. 42° 55′ 00″			20
W. 64° 51′ 00″	25	642	
95 m.			18
	40	606	
			84
	50	522	
			16
	75	483	
			1
	90	481	
Sect. XIII, 40. July 22	0	738	
N. 42° 36′ 00″			83
W. 64° 41′ 00″	25	531	
134 m.			26
	50	467	
			17
	75	425	
			6
	100	410	
			8
	125	389	

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XIII, 41. July 22	0	594	
N. 42° 17′ 00″			17
W. 64° 30′ 30″	25	551	
420 m.			52
	50	421	
			4
	75	410	
			7
	100	392	
			3
	150	376	
			2
	200	366	
			2
	300	345	
			1
	400	326	
Sect. XIII, 42. July 22	0	599	
N. 41° 58′ 00″			18
W. 64° 20′ 00″	25	554	
over 1,000 m.			47
	50	437	
			14
	75	402	
			6
	100	388	
			3
	150	371	
			3
	200	359	
			1
	300	345	
			2
	400	328	
Sect. XIII, 43. July 22	0	609	
N. 41° 38′ 30″			18
W. 64° 10′ 00″	25	563	
over 1,000 m.			21
	50	510	
			32
	75	430	
			2
	100	424	
			6
	150	396	
			1
	200	391	
			3
	300	362	
			2
	400	340	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XIII, XIV, 44. July 22	0	646	13
N. 41° 19′ 00″ W. 63° 59′ 00″	25	613	40
Over 1,000 m.	50	514	28
	75	445	17
	100	402	4
	150	380	2
	200	369	2
	300	348	2
	400	325	
Sect. XIV, 45. July 22	0	588	4
N. 42° 02′ 00″ W. 63° 43′ 00″	25	577	35
Over 1,000 m.	50	490	22
	75	434	10
	100	410	6
	150	382	3
	200	369	4
	300	328	1
	400	316	
Sect. XIV, 46. July 23	0	695	38
N. 42° 31′ 00″ W. 63° 31′ 30″	25	600	64
Over 1,000 m.	50	442	10
	75	418	4
	100	409	7
	150	375	1
	200	371	4
	300	333	0
	400	332	
Sect. XIV, 47. July 23	0	610	11
N. 43° 15′ 00″ W. 63° 13′ 30″	25	582	34
144 m.	50	498	34
	75	413	7
	100	396	6
	125	380	
Sect. XIV, 48. July 23	0	724	37
N. 43° 53′ 30″ W. 62° 58′ 30″	25	632	66
264 m.	50	468	12
	75	439	13
	100	407	12
	125	378	4
	150	369	3
	200	356	1
	250	349	
Sect. XIV, XV, 49. July 23	0	750	61
N. 44° 30′ 30″ W. 62° 43′ 00″	25	598	55
135 m.	40	516	12
	50	504	9
	75	482	4
	100	472	7
	125	454	
Sect. XV, 50. July 23	0	714	51
N. 44° 12′ 15″ W. 62° 35′ 00″	25	587	48
155 m.	50	467	12
	75	436	11
	100	408	6
	125	393	3
	150	386	
Sect. XV, 51. July 23	0	688	35
N. 43° 52′ 00″ W. 62° 18′ 00″	25	601	87
133 m.	40	471	16
	50	455	15
	75	417	9
	100	395	2
	125	389	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XV, 52. July 24	0	645	
			30
N. 43° 31′ 00″	25	569	
W. 62° 01′ 00″			58
	40	482	
95 m.			25
	50	457	
			20
	60	437	
			5
	75	430	
			13
	90	404	
Sect. XV, 53. July 24	0	618	
			35
N. 43° 14′ 30″	25	530	
W. 61° 48′ 00″			52
	40	452	
99 m.			7
	50	445	
			7
	75	428	
			5
	95	419	
Sect. XV, 54. July 24	0	670	
			43
N. 42° 57′ 30″	25	563	
W. 61° 34′ 00″			56
	50	422	
Over 1,000 m.			14
	75	387	
			1
	100	385	
			6
	150	357	
			1
	200	353	
			4
	300	317	
			1
	400	309	
Sect. XV, 55. July 24	0	712	
			70
N. 42° 41′ 15″	25	536	
W. 61° 21′ 00″			40
	50	437	
Over 1,000 m.			17
	75	395	
			1
	100	393	
			6
	150	361	
			1
	200	355	
			1
	300	345	
			3
	400	320	
Sect. XV, XVI, 56. July 24	0	768	
			94
N. 42° 16′ 00″	25	533	
W. 61° 01′ 00″			40
	50	434	
Over 1,000 m.			7
	100	398	
			5
	150	372	
			0
	200	371	
			3
	300	344	
			1
	400	339	
Sect. XVI, 57. July 24	0	679	
			50
N. 42° 57′ 30″	25	553	
W. 60° 56′ 00″			40
	50	452	
Over 1,000 m.			19
	75	405	
			8
	100	386	
			6
	150	356	
			3
	200	342	
			2
	300	322	
			1
	400	311	
Sect. XVI, 58. July 24	0	658	
			43
N. 43° 23′ 00″	25	550	
W. 60° 53′ 00″			42
	50	445	
187 m.			3
	75	437	
			18
	100	393	
			6
	125	378	
			4
	150	367	
			3
	175	359	
Sect. XVI, 59. July 25	0	642	
			5
N. 43° 48′ 30″	15	635	
W. 60° 50′ 00″			47
	30	565	
45 m.			37
	45	510	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XVI, 60. July 25 N. 44° 13′ 30″ W. 61° 14′ 00″ 98 m.	0	668	38
	25	573	42
	50	469	17
	75	427	6
	95	414	
Sect. XVI, 62. July 25 N. 44° 34′ 30″ W. 60° 47′ 00″ 62 m.	0	691	22
	25	637	62
	40	544	32
	50	512	15
	60	497	
Sect. XVI, 63. July 25 N. 44° 43′ 30″ W. 60° 46′ 00″ 55 m.	0	693	44
	25	584	35
	50	496	
Sect. XVI, 64. July 25 N. 45° 04′ 00″ W. 60° 46′ 00″ 120 m.	0	754	40
	25	653	41
	50	551	30
	75	476	6
	110	454	
Sect. XVI, XVII, 65. July 25 N. 45° 17′ 00″ W. 60° 42′ 30″ 105 m.	0	793	46
	10	747	86
	25	618	44
	50	509	5
	75	497	7
	100	480	
Sect. XVII, 66. July 25 N. 45° 08′ 00″ W. 60° 23′ 00″ 64 m.	0	732	4
	10	728	1
	25	726	79
	40	608	80
	50	528	37
	60	491	
Sect. XVII, 67. July 25 N. 44° 49′ 00″ W. 59° 40′ 00″ 205 m.	0	699	1
	10	698	58
	25	611	50
	50	486	10
	75	460	2
	100	455	3
	150	438	2
	200	429	
Sect. XVII, 68. July 26 N. 44° 32′ 00″ W. 59° 04′ 00″ 54 m.	0	673	18
	10	655	91
	25	518	13
	40	498	13
	50	485	
Sect. XVII, 69. July 26 N. 44° 19′ 15″ W. 58° 36′ 00″ 64 m.	0	693	1
	10	692	61
	25	641 558	74
	40	493 485	5
	50	484	
Sect. XVII, 70. July 26 N. 44° 05′ 00″ W. 58° 05′ 00″ Over 1,000 m.	0	659	52
	25	528	35
	50	441	16
	75	401	10
	100	375	5
	150	352	3
	200	338	1
	300	326	1
	400	315	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XVII, 71. July 26	0	605	46
N. 43° 57′ 00″ W. 57° 46′ 30″	25	545	39
Over 1,000 m.	50	448	21
	75	396	9
	100	373	
Sect. XVII, 72. July 26	0	708	75
N. 43° 51′ 30″ W. 57° 33′ 00″	25	521	36
Over 1,000 m.	50	430	12
	75	401	8
	100	381	4
	150	362	2
	200	353	2
	300	333	1
	400	321	
Sect. XVII, 73. July 26	0	703	66
N. 43° 46′ 00″ W. 57° 21′ 00″	25	539	46
Over 1,000 m.	50	424	12
	75	394	6
	100	379	
Sect. XVII, 74. July 26	0	697	72
N. 43° 41′ 00″ W. 57° 08′ 00″	25	517	35
Over 1,000 m.	50	429	10
	75	403	4
	100	392	3
	150	375	1
	200	369	2
	300	346	2
	400	329	
Sect. XVII, XVIII, 75. July 26	0	649	10
N. 43° 30′ 00″ W. 56° 43′ 00″	10	639	61
Over 1,000 m.	25	548	17
	50	506	37
	75	413	8
	100	394	3
	150	381	3
	200	367	2
	300	344	1
	400	329	
Sect. XVIII, 76. July 27	0	775	60
N. 43° 55′ 30″ W. 56° 13′ 00″	25	626	70
Over 1,000 m.	50	451	14
	75	417	11
	100	389	5
	150	362	4
	200	341	2
	300	322	1
	400	314	
Sect. XVIII, 77. July 27	0	747	80
N. 44° 21′ 15″ W. 55° 42′ 30″	10	667	96
Over 1,000 m.	25	523	36
	50	433	10
	75	407	6
	100	391	6
	150	362	4
	200	344	2
	300	326	1
	400	317	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XVIII, 78. July 27			
N. 44° 33′ 00″ W. 55° 29′ 00″	0	667	50
	50	418	9
Over 1,000 m.	75	395	10
	100	370	
Sect. XVIII, XIX, 79. July 27	0	617	43
N. 44° 47′ 00″ W. 55° 13′ 00″	10	574	33
	25	525	28
410 m.	50	456	20
	75	407	10
	100	381	4
	150	361	2
	200	350	2
	300	330	1
	400	318	
Sect. XIX, 80. July 27	0	637	21
N. 45° 17′ 00″ W. 55° 27′ 00″	10	616	37
	25	561	55
155 m.	40	478	33
	50	445	13
	75	412	2
	100	407	0
	125	406	0
	150	406	
Sect. XIX, 81. July 27	0	611	14
N. 45° 48′ 30″ W. 55° 43′ 00″	10	597	59
	25	508	29
56 m.	40	464	4
	54	459	
Sect. XIX, 82. July 27	0	616	0
N. 46° 11′ 00″ W. 55° 54′ 00″	10	616	43
	25	551	28
58 m.	40	509	64
	50	445	
Sect. XIX, XX, 83. July 28	0	625	18
N. 46° 32′ 00″ W. 56° 04′ 00″	25	580	49
	50	457	8
172 m.	75	437	4
	100	428	3
	125	420	3
	150	413	2
	170	409	
Sect. XX, 84. July 28	0	610	3
N. 46° 17′ 00″ W. 56° 37′ 00″	10	607	38
	25	550	41
60 m.	40	489	51
	50	438	
Sect. XX, 85. July 28	0	724	66
N. 46° 02′ 45″ W. 57° 09′ 00″	20	592	53
	40	487	35
492 m.	50	452	14
	75	418	9
	100	395	5
	150	368	4
	200	347	2
	300	324	1
	400	311	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Concluded.*

C. G. S. "ACADIA"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XX, 86. July 28	0	726	
			84
N. 45° 47′ 00″	25	515	
W. 57° 34′ 00″			30
	50	439	
455 m.			15
	75	402	
			1
	100	399	
			7
	150	362	
			2
	200	352	
			3
	300	326	
			2
	400	311	
Sect. XX, 87. July 28	0	726	
			85
N. 45° 38′ 30″	15	598	
W. 57° 59′ 30″			86
	25	512	
330 m.			31
	50	434	
			10
	75	408	
			4
	100	399	
			5
	150	372	
			4
	200	352	
			3
	300	325	
Sect. XX, 88. July 28	0	792	
			88
N. 45° 26′ 00″	25	573	
W. 58° 34′ 30″			33
	40	524	
130 m.			12
	50	512	
			12
	75	483	
			11
	100	456	
			16
	125	417	
Sect. XX, 89. July 28	0	775	
			44
N. 45° 16′ 00″	25	665	
W. 59° 04′ 00″			65
	50	503	
130 m.			8
	75	484	
			0
	100	484	
			4
	125	475	
Stat. 91. July 29	0	846	
			10
Canso Strait	10	836	
			1
50 m.	20	835	
			3
	30	832	
			1
	40	831	

TABLE 2.—Depth of the Isosteric surfaces in metres. Spring cruises

THE GULF OF ST. LAWRENCE.

"*" and "B" denotes that the isosteric surface in question has intersected the surface or the bottom, respectively, beyond the station.

					Section I.										Section II.				
Stat.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14	15	16	17	18
Depth m.	69	45	25	21	31	61	76	92	160–300	150–250	51	140	ca. 200	40	40	85	260	130	64
v_1 = 900......	*	*	2	0	6	0	4	*	*	*	*	*	*	3	3	*	*	*	*
v_1 = 800......	*	*	10	B	16	5	13	0	*	*	*	*	2	6	6	*	*	*	*
v_1 = 700......	*	*	B	B	24	9	19	13	*	*	*	*	11	10	10	15	*	*	*
v_1 = 600......	30	33	B	B	B	24	24	20	11	9	13	5	21	16	16	25	*	*	*
v_1 = 500......	B	B	B	B	B	B	B	65	57	51	44	46	47	33	33	38	49	52	34
v_1 = 400......	B	B	B	B	B	B	B	B	130	142	B	B	167	B	B	B	138	B	B

	Section III.								Section IV.					
Stat.	19	20	21	23	22	24	25	26	21	22	23	26	25	24
	82	250–400	ca. 500	ca. 100	55	40	63	40	27	195	355	389	271	45
v_1 = 900..............................	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 800..............................	*	*	*	*	*	*	*	*	0	3	9	6	*	*
v_1 = 700..............................	*	*	*	*	*	*	13	22	6	12	14	18	20	*
v_1 = 600..............................	*	*	*	*	*	29	20	34	17	19	21	26	27	16
v_1 = 500..............................	40	67	50	41	40	B	B	B	B	47	49	39	50	37
v_1 = 400.	B	161	150	B	B	B	B	B	B	111	135	139	136	B

TABLE 2.—Depth of the Isosteric surfaces in metres.—Spring cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANK.

	Section V.															
Stat.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Depth m.	25	60	146	173	73	45	109	51	106	740		Over 500				
v_1 = 600	12	17	13	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 500	B	B	39	51	7	45	29	60	25	*	*	*	*	*	*	*
v_1 = 400	B	B	B	129	B	B	92	B	101	87	74	125	53	80	93	70

	Section VI.								Section VII.					
Stat.	16	17	17*a*	18	19	20	21	22	22	23	24	25	26	27
Depth m.	Over 500					91	116	73	73	100	120	124	Ov. 500.	
v_1 = 600	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 500	*	*	*	*	*	*	*	*	*	*	*	*	5	*
v_1 = 400	70	41	51	73	68	B	86	B	B	B	B	106	93	81

	Section VIII.							Section IX.			
Stat.	27	28	29	30	31	32	33	33	34	35	36
Depth m.	Over 500		58	127	85	155	ca. 73	ca. 73	ca. 350	ca. 450	230
v_1 = 600	*	*	*	*	*	*	19	19	*	*	*
v_1 = 500	*	43	47	45	47	64	59	59	23	22	18
v_1 = 400	81	123	B	B	B	B	B	B	190	115	158

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises.

THE GULF OF ST. LAWRENCE.

	—		Section X.											
Stat.	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Depth m.	23	23	32	66	65	87	78	405	ca. 400	53	75	180	284	68
v_1 = 1100	*	*	2	*	*	*	*	*	*	*	*	*	*	*
v_1 = 1000	8	B	11	11	10	*	*	*	*	*	*	*	*	*
v_1 = 900	14	B	14	20	17	4	3	*	*	*	*	*	*	*
v_1 = 800	18	B	23	33	24	9	8	2	*	12	*	8	1	2
v_1 = 700	B	B	B	46	36	17	14	11	14	22	15	15	15	
v_1 = 600	B	B	B	54	45	27	22	30	22	30	22	21	21	12
v_1 = 500	B	B	B	B	59	64	46	48	42	48	41	35	35	34
v_1 = 400	B	B	B	B	B	B	B	130	143	B	B	134	150	B

	Section XI.					Section XII.						—			
Stat.	40	41	42	43	44	45	46	47	48	49	50	54	58	59	91
Depth m.	68	189	90	265	157	380	ca. 455	410	175	75	42	110	50	275	50
v_1 = 1100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 1000	*	*	*	*	*	*	*	*	*	*	*	6	*	*	*
v_1 = 900	*	*	*	*	*	*	*	*	*	13	16	7	*	*	*
v_1 = 800	2	*	*	*	*	*	*	6	8	18	26	9	*	*	B
v_1 = 700	7	16	15	15	15	*	*	24	18	23	32	11	11	10	B
v_1 = 600	12	24	28	25	24	30	25	42	31	31	39	21	21	20	B
v_1 = 500	34	52	49	49	46	57	45	69	50	61	B	61	45	46	B
v_1 = 400	B	162	B	154	152	198	149	148	115	B	B	B	B	B	B

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANKS.

	Section XIII.								Section XIV.					
Stat.	37	38	39	40	41	42	43	44	44	45	46	47	48	49
Depth m.	62	170	95	134	420	Over 1000			Over 1000			144	246	135
v_1 = 700	*	3	*	5	*	*	*	*	*	*	*	*	7	8
v_1 = 600	14	35	41	17	*	0	5	28	28	*	25	9	30	25
v_1 = 500	B	75	64	37	35	37	53	55	55	47	41	49	45	55
v_1 = 400	B	B	B	112	89	78	143	105	105	117	113	94	106	B

	Section XV.								Section XVI.								
Stat.	49	50	51	52	53	54	55	56	56	57	58	59	60	62	63	64	65
Depth m.	135	155	133	95	99	Over 1000			Over 1000		187	45	98	62	55	120	105
v_1 = 700	8	3	*	*	*	*	2	7	7	*	*	*	*	*	*	13	15
v_1 = 600	25	22	25	15	5	16	16	18	18	16	13	22	18	31	21	38	29
v_1 = 500	55	43	37	37	31	36	34	33	33	38	37	B	43	58	49	67	69
v_1 = 400	B	113	94	92	B	66	72	97	97	82	96	B	B	B	B	B	B

	Section XVII.											Section XVIII.				
Stat.	65	66	67	68	69	70	71	72	73	74	75	75	76	77	78	79
Depth m.	105	64	205	54	64	Over 1000						Over 1000				410
v_1 = 700	15	28	0	*	*	*	*	1	0	0	0	*	13	6	*	*
v_1 = 600	29	41	27	16	25	11	13	14	16	13	16	16	29	17	13	4
v_1 = 500	69	58	47	38	39	33	37	31	34	30	52	52	43	31	33	34
v_1 = 400	B	B	B	B	B	76	73	76	70	82	92	92	90	86	69	82

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANKS—*Concluded.*

	Section XIX.					Section XX.						
Stat.	79	80	81	82	83	83	84	85	86	87	88	89
Depth m.	410	155	56	58	172	172	60	492	455	330	130	130
v_1 = 700	*	*	*	*	*	*	*	4	3	3	10	17
v_1 = 600	4	14	8	14	14	14	12	19	15	15	22	35
v_1 = 500	34	36	28	41	41	41	37	37	30	29	60	54
v_1 = 400	82	B	B	B	B	B	B	95	92	97	B	B

TABLE 3.—Form for calculation of amount of solenoids in the sea.

1	2	3	4	5	6	7	8	9
Depth	v_{34}	v_{35}	a	a_m	A	ΣA	a_{100}	ΣA_{100}
0	522	514	r 8	r 4·5	r 113	r 6101	r 13	9840
25	498	497	r 1	r 4	r 100	r 5988	r 2	9658
50	469	462	r 7	r 18·5	r 463	r 5888	r 11	9497
75	461	431	r30	r 33	r 825	r 5425	r 48	8750
100	453	417	r36	r 23	r 4600	r 4600	r 58	7419
300	339	329	r10			0	r 16	0

TABLE 4.—Amount of solenoids between Stations IX. 34 and IX. 35.

Depth.	a	0·1 A	0·1 ΣA	$a_{100km.}$	$\Sigma A_{10km.}$
0	r 8	r 11	r 610	r 13	r 984
25	r 1	r 10	r 599	r 2	r 966
50	r 7	r 46	r 589	r 11	r 950
75	r 30	r 83	r 543	r 48	r 875
100	r 36	r 460	r 460	r 58	r 742
300	r 10		0	r 16	0

TABLE 5.—The Solenoids in Canadian waters.

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. I, 5–6, 47 km. 48 m.	0	r 26	r108	r353	r 55	r750	SE. 7·0
	10	r189	r150	r245	r402	r521	SE. 4·8
	20	r112	r 95	r 95	r238	r201	SE. 1·9
	30	r 77		0	r164	0	0
Sect. I, 6–7, 54 km. 68 m.	0	l 25	l 92	l 329	l 46	l 607	NW. 5·6
	10	l 157	l 141	l 237	l 290	l 438	NW. 4·1
	20	l 126	l 30	l 96	l 233	l 178	NW. 1·7
	25	r 8	l 5	l 66	r 15	l 122	NW. 1·1
	30	l 28	l 23	l 61	l 52	l 113	NW. 1·0
	40	l 17	l 19	l 38	l 31	l 70	NW. 0·7
	50	l 21	l 19	l 19	l 39	l 35	NW. 0·3
	60	l 18		0	l 33	0	0
Sect. I, 7–8, 57 km., 78 m.	0	r 132	r 118	r 542	r 231	r 951	SE. 8·7
	10	r 105	r 134	r 424	r 184	r 743	SE. 6·8
	20	r 163	r 184	r 290	r 285	r 508	SE. 4·7
	40	r 21	r 58	r 106	r 37	r 186	SE. 1·7
	60	r 37	r 48	r 48	r 65	r 84	SE. 0·8
	75	r 27		0	r 47	0	0
Sect. I, 8–9, 44 km., 100 m.	0	r 160	r 241	r 414	r 363	r 941	SE. 8·7
	25	r 33	r 123	r 173	r 75	r 393	SE. 3·6
	75	r 16	r 50	r 50	r 36	r 114	SE. 1·0
	100	r 24		0	r 54	0	0
Sect. I, 9–10, 75 km., 325 m.	0	r 11	r 29	r 81	r 15	r 108	SE. 1·0
	25	r 12	r 24	r 52	r 16	r 69	SE. 0·6
	50	r 7	r 33	r 28	r 9	r 37	SE. 0·3
	75	r 19	r 25	l 5	r 25	l 7	NW. 0·1
	100	r 1	l 30	l 30	r 1	l 40	NW. 0·4
	150	l 13		0	l 17	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	u.
Sect. I, 10–11 28 km., 90 m.	0	r 14	r 48	r 97	r 50	r 346	SE. 3·1
	25	r 25	r 49	r 49	r 89	r 175	SE. 1·6
	50	r 14		0	r 50	0	0
Sect. I, 11–12 49 km., 90 m.	0	l 13	r 16	r 17	l 27	r 35	SE. 0·3
	10	r 46	r 25	r 1	r 94	r 2	SE. 0
	25	l 13	l 24	l 24	l 27	l 49	NW. 0·4
	50	l 6		0	l 12	0	0
Sect. I, 12–13 34 km., 250 m.	0	l 189	l 280	l 348	l 556	l 1023	NW. 9·2
	25	l 35	l 42	l 68	l 103	l 200	NW. 1·8
	50	r 2	r 2	l 26	r 6	l 76	NW. 0·7
	75	l 1	l 19	l 28	l 3	l 82	NW. 0·7
	100	l 14	l 9	l 9	l 41	l 26	NW. 0·2
	125	r 7		0	r 21	l 0	0
Sect. I, 13–14 41 km., 110 m.	0	l 177	l 132	l 70	l 432	l 171	NW. 1·5
	20	r 45	r 62	r 62	r 110	r 151	SE. 1·4
	35	r 38		0	r 93	0	0
Sect. II, 14–15 83 km., 110 m.	0	r 227	r 75	l 115	r 273	l 139	NE. 1·3
	10	l 77	l 89	l 190	l 93	l 230	NE. 2·1
	20	l 101	l 101	l 101	l 122	l 122	NE. 1·1
	40	0		0	0	0	0
Sect. II, 15–16 49 km., 180 m.	0	r 189	r 192	r 287	r 386	r 585	SW. 5·3
	10	r 194	r 137	r 95	r 396	r 194	SW. 1·7
	20	r 80	r 45	l 42	l 163	l 86	NE. 0·8
	40	l 35	l 54	l 87	l 71	l 177	NE. 1·6
	60	l 19	l 33	l 33	l 39	l 67	NE. 0·6
	80	l 14		0	l 29	0	0
Sect. II, 16–17 47 km., 210 m.	0	r 16	r 28	l 85	r 34	l 181	NE. 1·6
	25	r 6	l 3	l 113	r 13	l 241	NE. 2·2
	50	l 8	l 30	l 110	l 17	l 234	NE. 2·1
	75	l 16	l 45	l 80	l 34	l 170	NE. 1·5
	100	l 20	l 35	l 35	l 43	l 75	NE. 0·7
	125	l 8		0	l 17	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. II, 17–18. 26 km., 100 m.	0	*l* 26	*l* 10	*r* 53	*l* 100	*r* 204	SW. 1·8
	25	*r* 18	*r* 63	*r* 63	*r* 69	*r* 242	SW. 2·2
	50	*r* 32		0	*r* 123	0	0
Sect. III, 19–20. 42 km., 130 m.	0	*r* 3	*l* 29	*l* 264	*r* 7	*l* 628	SE. 5·8
	25	*l* 26	*l* 93	*l* 235	*l* 62	*l* 559	SE. 5·1
	50	*l* 48	*l* 53	*l* 142	*l* 114	*l* 338	SE. 3·1
	60	*l* 58	*l* 89	*l* 89	*l* 138	*l* 212	SE. 2·0
	80	*l* 31		0	*l* 74	0	0
Sect. III, 20–21. 39 km., 360 m.	0	*r* 17	*r* 39	*r* 330	*r* 44	*r* 846	NW. 7·8
	25	*r* 14	*r* 66	*r* 291	*r* 36	*r* 746	NW. 6·9
	50	*r* 39	*r* 69	*r* 225	*r* 100	*r* 577	NW. 5·3
	75	*r* 16	*r* 31	*r* 156	*r* 41	*r* 400	NW. 3·7
	100	*r* 9	*r* 125	*r* 125	*r* 23	*r* 321	NW. 3·0
	200	*r* 16		0	*r* 41	0	0
Sect. III, 21–23. 44 km., 400 m.	0	*l* 42	*l* 55	*r* 62	*l* 95	*r* 141	NW. 1·3
	20	*l* 13	*l* 2	*r* 117	*l* 30	*r* 266	NW. 2·5
	40	*r* 11	*r* 16	*r* 119	*r* 25	*r* 270	NW. 2·5
	50	*r* 22	*r* 48	*r* 103	*r* 50	*r* 234	NW. 2·2
	75	*r* 16	*r* 55	*r* 55	*r* 36	*r* 124	NW. 1·1
	100	*r* 28		0	*r* 64	0	0
Sect. III, 23–22. 11 km., 70 m.	0	*r* 5	*r* 10	*r* 9	*r* 45	*r* 82	NW. 0·8
	20	*r* 5	*r* 10	*l* 1	*r* 45	*l* 9	SE. 0·1
	40	*r* 5	*l* 11	*l* 11	*r* 45	*l* 100	SE. 0·9
	55	*l* 19		0	*l* 173	0	0
Sect. III, 22–24. 65 km., 45 m.	0	*l* 102	*l* 190	*l* 307	*l* 157	*l* 473	SE. 4·4
	20	*l* 88	*l* 117	*l* 117	*l* 136	*l* 180	SE. 1·7
	35	*l* 68		0	*l* 105	0	0

TABLE 5.—The Solenoids in Canadian waters.—*Continued*

——	Depth.		0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. III, 24–25 .... 51 km., 50 m.	0	l 79		l 27	l 155	l 53	SE. 0·5
			l 77				
	10	l 74		r 50	l 145	r 98	NW. 0·9
			l 15				
	20	r 44		r 65	r 86	r 127	NW. 1·2
			r 47				
	30	r 49		18	r 96	r 35	NW. 0·3
			r 18				
	35	r 24		0	r 47	0	0
Sect. III, 25–26 .... 66 km., 60 m.	0	l 36		l 234	l 54	l 354	SE. 3·3
			l 34				
	10	l 32		l 200	l 48	l 303	SE. 2·9
			l 75				
	20	l 118		l 125	l 179	l 189	SE. 1·8
			l 125				
	35	l 49		0	l 74		0
Sect. IV, 21–22 .... 7 km., 50 m.	0	l 21		l 126	l 300	l1802	NW. 16·4
			l 55				
	10	l 89		l 71	l 1271	l 1015	NW. 9·2
			l 71				
	24	l 12		0	l 171	0	0
Sect. IV, 22–23 .... 20 km., 240 m.	0	r 3		l 229	r 15	l1145	NW. 10·4
			l 31				
	10	l 65		l 198	l 325	l 990	NW. 9·0
			l 44				
	20	l 22		l 154	l 110	l 770	NW. 7·0
			l 20				
	30	l 18		l 134	l 90	l 670	NW. 6·1
			r 23				
	50	l 5		l 111	l 25	l 555	NW. 5·1
			r 9				
	75	r 12		l 120	r 60	l 600	NW. 5·5
			l 2				
	100	l 13		l 118	l 65	l 590	NW. 5·4
			l 41				
	125	l 20		l 77	l 100	l 385	NW. 3·5
			l 41				
	150	l 13		l 36	l 65	l 180	NW. 1·6
			l 36				
	190	l 5		0	l 25	0	0
Sect. IV, 23–26 .... 19 km., 350 m.	0	l 2		r 105	l 11	r 553	SE. 5·0
			r 5				
	10	r 13		r 100	r 68	r 526	SE. 4·8
			l 30				
	20	l 74		r 130	l 389	r 684	SE. 6·2
			l 25				
	30	r 24		r 155	r 126	r 816	SE. 7·4
			r 59				
	50	r 35		r 96	r 184	r 505	SE. 4·6
			r 59				
	75	r 12		r 37	r 63	r 195	SE. 1·8
			r 22				
	100	r 6		r 15	r 32	r 79	SE. 0·7
			0				
	150	l 6		r 15	l 32	r 79	SE. 0·7
			l 10				
	250	r 4		r 25	r 21	r 132	SE. 1·2
			r 25				
	350	r 1		0	r 5	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. IV, 26–25. 16 km., 256 m.	0	*r* 81		*l* 46	*r* 506	*l* 289	NW. 2·6
			r 62				
	10	*r* 43		*l* 108	*r* 269	*l* 675	NW. 6·1
			r 12				
	20	*l* 20		*l* 120	*l* 125	*l* 750	NW. 6·8
			l 19				
	30	*l* 18		*l* 101	*l* 113	*l* 631	NW. 5·7
			l 55				
	50	*l* 37		*l* 46	*l* 231	*l* 288	NW. 2·6
			l 65				
	75	*l* 15		*r* 19	*l* 94	*r* 119	SE. 1·1
			l 14				
	100	*r* 4		*r* 33	*r* 25	*r* 206	SE. 1·9
			r 13				
	150	*r* 1		*r* 20	*r* 6	*r* 125	SE. 1·1
			r 20				
	250	*r* 3		0	*r* 19	0	0
Sect. IV, 25–24. 11 km., 130 m.	0	*r* 103		*r* 318	*r* 936	*r* 2890	SE. 26·0
			r 117				
	10	*r* 131		*r* 201	*r*1191	*r* 1827	SE. 16·4
			r 120				
	20	*r* 109		*r* 81	*r* 991	*r* 736	SE. 6·6
			r 56				
	30	*r* 3		*r* 25	*r* 27	*r* 227	SE. 2·0
			r 25				
	42	*r* 38		0	*r* 345	0	0
Sect. V, 1–2. 17 km., 27 m.	0	*r* 9		*l* 10	*r* 53	*l* 59	NE. 0·6
			r 9				
	10	*r* 8		*l* 19	*r* 47	*l* 112	NE. 1·1
			l 19				
	20	*l* 45		0	*l* 265	0	0
Sect. V, 2–3. 38 km., 90 m.	0	*l* 3		*r* 143	*l* 8	*r* 376	SW. 3·7
			l 2				
	10	*l* 1		*r* 145	*l* 3	*r* 381	SW. 3·7
			r 3				
	20	*r* 7		*r* 142	*r* 18	*r* 373	SW. 3·7
			r 25				
	30	*r* 42		*r* 117	*r* 110	*r* 308	SW. 3·0
			r 49				
	40	*r* 56		*r* 68	*r* 147	*r* 179	SW. 1·8
			r 68				
	55	*r* 34		0	*r* 89	0	0
Sect. V, 3–4. 65 km., 170 m.	0	*r* 42		*r* 131	*r* 65	*r* 201	SW. 2·0
			r 41				
	10	*r* 40		*r* 90	*r* 62	*r* 139	SW. 1·4
			r 37				
	20	*r* 34		*r* 53	*r* 52	*r* 82	SW. 0·8
			r 9				
	30	*l* 16		*r* 44	*l* 25	*r* 68	SW. 0·7
			l 21				
	40	*l* 26		*r* 65	*l* 40	*r* 100	SW. 1·0
			l 22				
	50	*l* 17		*r* 87	*l* 26	*r* 134	SW. 1·3
			l 4				
	60	*r* 9		*r* 91	*r* 14	*r* 140	SW. 1·4
			r 19				
	75	*r* 16		*r* 72	*r* 25	*r* 111	SW. 1·1
			r 25				
	90	*r* 17		*r* 47	*r* 26	*r* 72	SW. 0·7
			r 47				
	110	*r* 30		0	*r* 46	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. V, 4–5. 56 km., 140 m.	0	r 59	r 63	r 406	r 106	r 725	SW. 7·2
	10	r 66	r 105	r 343	r 118	r 612	SW. 6·1
	25	r 74	r 146	r 238	r 132	r 425	SW. 4·2
	50	r 43	r 92	r 92	r 77	r 164	SW. 1·6
	70	r 49		0	r 88	0	0
Sect. V, 5–6. 56 km., 120 m.	0	l 14	l 17	l 121	l 25	l 216	NE. 2·1
	10	l 21	l 27	l 104	l 38	l 186	NE. 1·8
	20	l 33	l 37	l 77	l 59	l 138	NE. 1·4
	30	l 40	l 40	l 40	l 72	l 71	NE. 0·7
	40	l 40		0	l 72	0	0
Sect. V, 6–7. 56 km., 40 m.	0	l 9	l 6	r 37	l 16	r 66	SW. 0·7
	10	l 3	l 1	r 43	l 5	r 77	SW. 0·8
	20	r 2	r 11	r 44	r 4	r 79	SW. 0·8
	30	r 20	r 33	r 33	r 36	r 59	SW. 0·6
	40	r 45		0	r 81	0	0
Sect. V, 6–8. 64 km., 40 m.	0	l 20	l 20	l 28	l 31	l 44	N. 0·4
	10	l 19	l 12	l 8	l 30	l 12	N. 0·1
	20	l 5	r 1	r 4	l 8	r 6	S. 0·1
	30	r 7	r 3	r 3	r 11	r 5	S. 0·0
	40	l 1		0	l 2	0	0
Sect. V, 7–8. 30 km., 50m.	0	l 11	l 14	l 124	l 37	l 413	W. 4·1
	10	l 16	l 11	l 110	l 53	l 366	W. 3·6
	20	l 7	l 10	l 99	l 23	l 330	W. 3·3
	30	l 13	l 30	l 89	l 43	l 296	W. 2·9
	40	l 46	l 59	l 59	l 153	l 196	W. 2·0
	50	l 72		0	l 240	0	0
Sect. V, 8–9. 55 km., 50 m.	0	r 29	r 56	r 198	r 53	r 360	SW. 3·6
	25	r 16	r 66	r 142	r 29	r 258	SW. 2·6
	40	r 72	r 76	r 76	r 131	r 138	SW. 1·4
	50	r 80		0	r 146	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. V, 9–10 .... 30 km., 100 m.	0	*r* 22	*r* 59	*r* 5	*r* 73	*r* 17	SW. 0·2
	25	*r* 25	*l* 6	*l* 54	*r* 83	*l* 180	NE. 1·8
	50	*l* 30	*l* 51	*l* 48	*l* 100	*l* 160	NE. 1·6
	75	*l* 11	*r* 3	*r* 3	*l* 37	*r* 10	SW. 0·1
	100	*r* 13		0	*r* 43	0	0
Sect. V, 10–11 .... 37 km., >400 m.	0	*r* 8	*r* 17	*r* 131	*r* 22	*r* 354	SW. 3·5
	25	*r* 5	*r* 1	*r* 114	*r* 14	*r* 308	SW. 3·1
	50	*l* 4	*r* 38	*r* 113	*l* 11	*r* 305	SW. 3·0
	75	*r* 34	*r* 55	*r* 75	*r* 92	*r* 203	SW. 2·0
	100	*r* 10	*r* 55	*r* 20	*r* 27	*r* 54	SW. 0·5
	150	*r* 12	*r* 45	*l* 35	*r* 32	*l* 95	NE. 0·9
	300	*l* 6	*l* 80	*l* 80	*l* 16	*l* 216	NE. 2·1
	400	*l* 10		0	*l* 27	0	0
Sect. V, 11–12 .... 67 km., >400 m.	0	*r* 1	*r* 51	*l* 397	*r* 1	*l* 592	NE. 5·9
	25	*r* 40	*r* 85	*l* 448	*r* 60	*l* 817	NE. 8·2
	50	*r* 28	*r* 10	*l* 533	*r* 42	*l* 794	NE. 7·9
	75	*l* 20	*l* 63	*l* 543	*l* 30	*l* 809	NE. 8·1
	100	*l* 30	*l* 150	*l* 480	*l* 45	*l* 715	NE. 7·2
	150	*l* 29	*l* 270	*l* 330	*l* 43	*l* 492	NE. 4·9
	300	*l* 7	*l* 60	*l* 60	*l* 10	*l* 89	NE. 0·9
	400	*l* 5		0	*l* 7	0	0
Sect. V, 12–13 .... 28 km., >400 m.	0	*l* 29	*l* 71	*r* 404	*l* 104	*r*1442	SW. 14·4
	25	*l* 28	*l* 4	*r* 475	*l* 100	*r*1696	SW. 17·0
	50	*r* 25	*r* 70	*r* 479	*r* 89	*r*1710	SW. 17·1
	75	*r* 31	*r* 91	*r* 409	*r* 111	*r*1460	SW. 14·6
	100	*r* 42	*r* 180	*r* 318	*r* 150	*r*1135	SW. 11·4
	150	*r* 30	*r* 138	*r* 138	*r* 107	*r* 493	SW. 4·9
	200	*r* 25		0	*r* 89	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

———	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. V, 13-14............................ 69 km., >400 m.	0	r 57		l 79	r 83	l 115	NE. 1·2
			r 91				
	25	r 16		l 170	r 23	l 247	NE. 2·5
			l 15				
	50	l 28		l 155	l 41	l 225	NE. 2·3
			l 89				
	75	l 43		l 66	l 62	l 96	NE. 1·0
			l 53				
	100	0		l 13	0	l 19	NE. 0·2
			l 3				
	150	l 1		l 10	l 1	l 15	NE. 0·2
			l 10				
	200	l 3		0	l 4	0	0
Sect. V, 14-15.................... .... 98 km. >400 m.	0	l 21		l 479	l 21	l 489	NE. 4·9
			l 60				
	25	l 27		l 419	l 28	l 427	NE. 4·3
			l 38				
	50	l 3		l 381	l 3	l 388	NE. 3·9
			l 6				
	75	2		l 375	l 2	l 382	NE. 3·8
			l 30				
	100	22		l 345	l 22	l 351	NE. 3·5
			l 90				
	150	14		l 255	l 14	l 260	NE. 2·6
			l 180				
	300	10		l 75	l 10	l 77	NE. 0·8
			l 75				
	400	5		0	l 5	0	0
Sect. V, 15-16............................ 97 km., >400 m.	0	r 61		l 186	r 63	l 192	NE. 1·9
			r 159				
	25	61		l 345	r 63	l 355	NE. 3·6
			r 113				
	50	29		l 458	r 30	l 472	NE. 4·8
			r 78				
	75	33		l 536	r 34	l 552	NE. 5·6
			r 39				
	100	3		l 575	l 3	l 592	NE. 6·0
			l 120				
	200	21		l 455	l 22	l 469	NE. 4·7
			l 230				
	300	l 25		l 225	l 26	l 232	NE. 2·3
			l 225				
	400	20		0	l 21	0	0
Sect. VI, 16-17............................ 70 km., >400 m.	0	r 4		r 3	r 6	r 4	E. 0·0
			r 10				
	25	r 4		l 7	r 6	l 10	W. 0·1
			r 14				
	50	r 7		l 21	r 10	l 30	W. 0·3
			r 12				
	75	r 3		l 33	r 4	l 47	W. 0·5
			l 1				
	100	l 4		l 32	l 6	l 46	W. 0·5
			0				
	150	r 4		l 32	r 6	l 46	W. 0·5
			r 13				
	200	r 1		l 45	r 1	l 64	W. 0·6
			l 5				
	300	l 2		l 40	l 3	l 57	W. 0·6
			l 40				
	400	l 6		0	l 9	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	√0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. VI, 17–18........................... 76 km., >400 m.	0	l 53		r 539	l 70	r 709	E. 7·1
			l 129				
	25	l 50		r 668	l 66	r 878	E. 8·8
			l 124				
	50	l 49		r 792	l 65	r1051	E. 10·5
			l 61				
	75	0		r 853	0	r1122	E. 11·2
			r 15				
	100	r 12		r 838	r 16	r1102	E. 11·0
			r 72				
	150	r 17		r 765	r 22	r1007	E. 10·1
			r 405				
	300	r 37		r 360	r 49	r 474	E. 4·7
			r 360				
	400	r 35		0	r 46	0	0
Sect. VI, 17a–18........................... 29 km., >400 m.	0	l 24		l 159	l 83	l 549	W. 5·4
			l 139				
	75	l 13		l 20	l 45	l 69	W. 0·7
			l 20				
	100	l 3		0	l 10	0	0
Sect. VI, 18–19........................... 44 km., >400 m.	0	l 2		l 278	l 5	l 631	W. 6·2
			l 11				
	25	l 7		l 267	l 16	l 606	W. 6·0
			l 19				
	50	l 8		l 248	l 18	l 563	W. 5·5
			r 14				
	75	r 19		l 262	r 43	l 595	W. 5·9
			r 33				
	100	r 7		l 295	r 16	l 670	W. 6·6
			r 8				
	150	l 4		l 303	l 9	l 688	W. 6·8
			l 128				
	300	l 13		l 175	l 30	l 397	W. 3·9
			l 175				
	400	l 22		0	l 50	0	0
Sect. VI, 19–20........................... 45 km., >400 m....................	0	l 1		l 23	l 2	l 51	W. 0·5
			r 1				
	25	r 2		l 24	r 4	l 53	W. 0·5
			r 14				
	50	r 9		l 38	r 20	l 84	W. 0·8
			l 38				
	75	l 39		0	l 87	0	0
Sect. VI, 20–21........................... 56 km., 110 m.	0	r 10		r 112	r 18	r 200	E. 1·9
			r 39				
	25	r 21		r 73	r 38	r 131	E. 1·3
			r 43				
	50	13		r 30	r 23	r 54	E. 0·5
			r 30				
	75	r 11		0	r 20	0	0
Sect. VI, 21–22........................... 43 km., 85 m.	0	7		l 38	l 16	l 89	W. 0·9
			l 20				
	20	13		l 18	l 30	l 42	W. 0·4
			l 25				
	40	l 12		r 7	l 28	r 16	E. 0·2
			l 2				
	50	r 7		r 9	r 16	r 21	E. 0·2
			r 9				
	65	5		0	r 12	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	$a.$	0·1 A.	0·1 ΣA.	$a_{100km.}$	ΣA $_{10km}$	$u.$
Sect. VII, 22–23 .... 60 km., 80 m.	0	*r* 1	*l* 3	*l* 31	*r* 2	*l* 52	SE. 0·5
	25	*l* 4	*l* 18	*l* 28	*l* 7	*l* 47	SE. 0·5
	50	*l* 10	*l* 10	*l* 10	*l* 17	*l* 17	SE. 0·2
	60	*l* 10		0	*l* 17	0	0
Sect. VII, 23–24 .... 54 km., 140 m.	0	*l* 6	*l* 18	*l* 13	*l* 11	*l* 24	SE. 0·2
	50	*l* 1	*r* 5	*r* 5	*l* 2	*r* 9	NW. 0·1
	75	*r* 5		0	*r* 9	0	0
Sect. VII, 24–25 .... 49 km., 100 m.	0	*r* 8	*r* 65	*r* 138	*r* 16	*r* 282	NW. 2·7
	50	*r* 18	*r* 73	*r* 73	*r* 37	*r* 149	NW. 1·4
	100	*r* 11		0	*r* 22	0	0
Sect. VII, 25–26 .... 62 km., > 400 m.	0	*l* 50	*l* 98	*l* 212	*l* 81	*l* 341	SE. 3·3
	25	*l* 28	*l* 84	*l* 114	*l* 45	*l* 184	SE. 1·8
	50	*l* 39	*l* 65	*l* 30	*l* 63	*l* 48	SE. 0·5
	100	*r* 13	*r* 35	*r* 35	*r* 21	*r* 56	NW. 0·5
	120	*r* 22		0	*r* 35	0	0
Sect. VII, 26–27 .... 60 km., >400 m.	0	*r* 9	*r* 23	*l* 147	*r* 15	*l* 245	SE. 2·4
	25	*r* 9	*r* 35	*l* 170	*r* 15	*l* 284	SE. 2·8
	50	*r* 19	*r* 73	*l* 205	*r* 32	*l* 342	SE. 3·4
	100	*r* 10	*l* 33	*l* 278	*r* 17	*l* 464	SE. 4·5
	150	*l* 23	*l* 210	*l* 245	*l* 38	*l* 409	SE. 4·0
	300	*l* 5	*l* 35	*l* 35	*l* 8	*l* 58	SE. 0·6
	400	*l* 2		0	*l* 3	0	0
Sect. VIII, 27–28 .... 42 km., >400 m.	0	*l* 44	*l* 116	*l* 785	*l* 105	*l* 1868	SW. 18·4
	25	*l* 49	*l* 133	*l* 669	*l* 117	*l* 1592	SW. 15·6
	50	*l* 57	*l* 126	*l* 536	*l* 136	*l* 1276	SW. 12·6
	75	*l* 44	*l* 107	*l* 410	*l* 105	*l* 976	SW. 9·6
	100	*l* 42	*l* 115	*l* 303	*l* 100	*l* 721	SW. 7·1
	150	*l* 4	*l* 128	*l* 188	*l* 12	*l* 447	SW. 4·4
	300	*l* 13	*l* 60	*l* 60	*l* 31	*l* 143	SW. 1·4
	400	*r* 1		0	*r* 2	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	u.
Sect. VIII, 28–29........................ 61 km., 90 m.	0	*l* 8	*l* 5	*l* 5	*l* 13	*l* 8	SW. 0·1
	50	*r* 6		0	*r* 10	0	0
Sect. VIII, 29–30........................ 57 km., 60 m.	0	*l* 13	*l* 165	*l* 165	*l* 23	*l* 289	SW. 2·8
	50	*l* 53		0	*l* 93	0	0
Sect. VIII, 30–31........................ 64 km., 140 m.	0	*l* 21	*l* 53	*l* 79	*l* 33	*l* 123	SW. 1·2
	25	*l* 21	*l* 30	*l* 26	*l* 33	*l* 41	SW. 0·4
	50	*l* 3	*r* 4	*r* 4	*l* 5	*r* 6	NE. 0·1
	75	*r* 6		0	*r* 9	0	0
Sect. VIII, 31–32........................ 68 km., 160 m.	0	*r* 12	*r* 54	*r* 26	*r* 18	*r* 38	NE. 0·4
	25	*r* 31	*r* 8	*l* 28	*r* 46	*l* 41	SW. 0·4
	50	*l* 24	*l* 36	*l* 36	*l* 35	*l* 53	SW. 0·5
	75	*l* 5		0	*l* 7	0	0
Sect. VIII, 32–33........................ 60 km., 75 m.	0	*l* 58	*l* 121	*l* 148	*l* 97	*l* 247	SW. 2·3
	25	*l* 39	*l* 48	*l* 27	*l* 65	*l* 45	SW. 0·4
	50	*r* 1	*r* 21	*r* 21	*r* 2	*r* 35	NE. 0·3
	75	*r* 16		0	*r* 27	0	0
Sect. IX, 33–34........................ 61 km., 180 m.	0	*r* 108	*r* 226	*r* 446	*r* 177	*r* 731	SE. 6·9
	25	*r* 73	*r* 150	*r* 220	*r* 120	*r* 361	SE. 3·4
	50	*r* 47	*r* 70	*r* 70	*r* 77	*r* 115	SE. 1·1
	75	*r* 9		0	*r* 15	0	0
Sect. IX, 34–35........................ 62 km., >400 m.	0	*r* 8	*r* 11	*r* 610	*r* 13	*r* 984	SE. 9·2
	25	*r* 1	*r* 10	*r* 599	*r* 2	*r* 966	SE. 9·1
	50	*r* 7	*r* 46	*r* 589	*r* 11	*r* 950	SE. 8·9
	75	*r* 30	*r* 83	*r* 543	*r* 48	*r* 875	SE. 8·2
	100	*r* 36	*r* 460	*r* 460	*r* 58	*r* 742	SE. 7·0
	300	*r* 10		0	*r* 16	0	0
Sect. IX, 35–36........................ 55 km., 230 m.	0	*l* 7	*l* 3	*l* 155	*l* 13	*l* 282	NW. 2·6
	25	*r* 5	*r* 11	*l* 152	*r* 9	*l* 277	NW. 2·6
	50	*r* 4	*l* 13	*l* 163	*r* 7	*l* 297	NW. 2·8
	75	*l* 14	*l* 150	*l* 150	*l* 25	*l* 273	NW. 2·5
	150	*l* 26		0	*l* 47	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. X, 29–30. 48 km., 50 m.	0	r 109		r 37	r 227	r 77	SE. 0·7
			r 67				
	10	r 25		l 30	r 52	l 62	NW. 0·6
			l 30				
	25	l 65		0	l 135	0	0
Sect. X, 30–31. 42 km., 60 m.	0	l 55		r 325	l 131	r 774	SE. 7·2
			l 24				
	10	r 7		r 349	r 17	r 831	SE. 7·7
			r 55				
	25	r 66		r 294	r 157	r 700	SE. 6·5
			r 114				
	40	r 86		r 180	r 205	r 428	SE. 4·0
			r 105				
	50	r 124		r 75	r 295	r 179	SE. 1·7
			r 75				
	60	r 26		0	r 62	0	0
Sect. X, 31–32. 35 km., 60 m.	0	r 86		r 713	r 246	r2039	SE. 18·8
			r 156				
	10	r 226		r 557	r 646	r1593	SE. 14·7
			r 302				
	25	r 177		r 255	r 506	r 729	SE. 6·7
			r 248				
	50	r 21		r 7	r 60	r 20	SE. 0·2
			r 7				
	60	l 7		0	l 20	0	0
Sect. X, 32–33. 50 km., 75 m.	0	r 28		r 253	r 56	r 506	SE. 4·7
			r 25				
	10	r 22		r 228	r 44	r 456	SE. 4·2
			r 47				
	25	r 40		r 181	r 80	r 362	SE. 3·3
			r 83				
	50	r 27		r 98	r 54	r 196	SE. 1·8
			r 98				
	75	r 51		0	r 102	0	0
Sect. X, 33–34. 28 km., 95 m.	0	r 126		l 18	r 450	l 64	NW. 0·6
			r 86				
	10	r 46		l 104	r 164	l 371	NW. 3·4
			l 10				
	25	l 59		l 94	l 211	l 336	NW. 3·1
			l 73				
	50	l 1		l 21	l 4	l 75	NW. 0·7
			l 21				
	75	l 16		0	l 57	0	0
Sect. X, 34–35. 37 km., 390 m.	0	r 53		r 1	r 143	r 3	SE. 0·0
			r 2				
	10	l 50		l 1	l 135	l 3	NW. 0·0
			r 6				
	25	r 58		l 7	r 157	l 19	NW. 0·2
			r 96				
	50	r 17		l 103	r 46	l 278	NW. 2·5
			r 28				
	75	r 5		l 131	r 14	l 354	NW. 3·2
			r 2				
	100	l 4		l 133	l 11	l 359	NW. 3·3
			l 43				
	150	l 13		l 90	l 35	l 243	NW. 2·2
			l 42				
	200	l 4		l 48	l 11	l 130	NW. 1·2
			l 30				
	300	l 2		l 18	l 5	l 48	NW. 0·4
			l 18				
	350	l 5		0	l 14	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	*u.*
Sect. X, 35–36. 46 km., 270 m.	0	*l* 52	*l* 61	*l* 344	*l* 113	*l* 746	NW. 6·8
	10	*l* 70	*l* 127	*l* 283	*l* 152	*l* 614	NW. 5·6
	25	*l* 99	*l* 156	*l* 156	*l* 215	*l* 339	NW. 3·1
	50	*l* 26		0	*l* 56	0	0
Sect. X, 36–37. 36 km., 50 m.	0	*r* 42	*r* 47	*r* 351	*r* 117	*r* 975	SE. 8·9
	10	*r* 52	*r* 128	*r* 304	*r* 145	*r* 845	SE. 7·7
	25	*r* 118	*r* 176	*r* 176	*r* 328	*r* 489	SE. 4·4
	50	*r* 23		0	*r* 64	0	0
Sect. X, 37–38. 41 km., 100 m.	0	*l* 31	*l* 27	*r* 38	*l* 76	*r* 92	SE. 0·8
	10	*l* 23	*r* 2	*r* 65	*l* 56	*r* 159	SE. 1·4
	25	*r* 26	*r* 48	*r* 63	*r* 63	*r* 154	SE. 1·4
	50	*r* 12	*r* 15	*r* 15	*r* 29	*r* 37	SE. 0·3
	70	*r* 3		0	*r* 7	0	0
Sect. X, 38–39. 32 km., 240 m.	0	*r* 15	*r* 11	*l* 30	*r* 47	*l* 94	NW. 0·8
	10	*r* 7	*r* 2	*l* 41	*r* 22	*l* 128	NW. 1·2
	25	*l* 4	*l* 5	*l* 43	*l* 13	*l* 134	NW. 1·2
	50	0	*l* 4	*l* 38	0	*l* 119	NW. 1·1
	75	*l* 3	*l* 4	*l* 34	*l* 9	*l* 106	NW. 1·0
	100	0	*l* 20	*l* 30	0	*l* 94	NW. 0·8
	150	*l* 8	*l* 10	*l* 10	*l* 25	*l* 31	NW. 0·3
	175	0		0	0	0	0
Sect. X, 39–40. 37 km., 120 m.	0	*l* 47	*r* 64	*r* 175	*l* 127	*r* 473	SE. 4·2
	10	*r* 175	*r* 135	*r* 111	*r* 473	*r* 300	SE. 2·7
	25	*r* 5	*l* 3	*l* 24	*r* 14	*l* 65	NW. 0·6
	50	*l* 7	*l* 21	*l* 21	*l* 19	*l* 57	NW. 0·5
	65	*l* 21		0	*l* 57	0	0
Sect. XI, 40–41. 51 km., 100 m.	0	*r* 72	*l* 44	*l* 390	*r* 141	*l* 764	NE. 6·8
	10	*l* 160	*l* 176	*l* 346	*l* 314	*l* 678	NE. 6·1
	25	*l* 75	*l* 138	*l* 170	*l* 147	*l* 333	NE. 3·0
	50	*l* 35	*l* 32	*l* 32	*l* 69	*l* 63	NE. 0·6
	65	*l* 7		0	*l* 14	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA 10km	u.
Sect. XI, 41–42	0	r 27		r 67	r 68	r 168	SW. 1·5
40 km., 80 m.			r 27				
	10	r 27		r 40	r 68	r 100	SW. 0·9
			r 7				
	25	l 18		r 33	l 45	r 83	SW. 0·7
			l 13				
	50	r 8		r 46	r 20	r 115	SW. 1·0
			r 32				
	75	r 18		r 14	r 45	r 35	SW. 0·3
			r 14				
	85	r 9		0	r 23	0	0
Sect. XI., 42–43	0	0		r 14	0	r 27	SW. 0·2
52 km., 210 m.			0				
	10	0		r 14	0	r 27	SW. 0·2
			r 11				
	25	r 14		r 3	r 27	r 6	SW. 0·1
			r 18				
	50	0		l 15	0	l 29	NE. 0·3
			l 10				
	75	l 8		l 5	l 15	l 10	NE. 0·1
			l 5				
	85	l 2		0	l 4	0	0
Sect. XI, 43–44	0	l 4		r 22	l 9	r 51	SW. 0·5
43 km., 210 m.			l 4				
	10	l 3		r 26	l 7	r 60	SW. 0·5
			r 7				
	25	r 12		r 19	r 28	r 44	SW. 0·4
			r 29				
	50	r 11		l 10	r 26	l 23	NE. C·2
			r 6				
	75	l 6		l 16	l 14	l 37	NE. 0·3
			l 11				
	100	l 3		l 5	l 7	l 12	NE. 0·1
			l 5				
	150	r 1		0	r 2	0	0
Sect. XII, 45–46	0	l 30		r 392	l 107	r 1403	NW. 13·0
28 km., >400 m.			l 8				
	25	r 24		r 400	r 86	r 1432	NW. 13·3
			r 75				
	50	r 36		r 325	r 129	r 1164	NW. 10·8
			r 61				
	75	r 13		r 264	r 46	r 945	NW. 8·7
			r 36				
	100	r 16		r 228	r 57	r 814	NW. 7·5
			r 132				
	150	r 37		r 95	r 132	r 339	NW. 3·1
			r 175				
	200	r 33		l 80	r 118	l 286	SE. 2·6
			r 70				
	300	l 19		l 150	l 68	l 536	SE. 5·0
			l 150				
	400	l 11		0	l 39	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	u.
Sect. XII, 46–47 .... 37 km., >400 m.	0	l 143	l 299	l 941	l 386	l 2541	SE. 23·6
	25	l 96	l 214	l 642	l 259	l 1735	SE. 16·1
	50	l 75	l 128	l 428	l 203	l 1157	SE. 10·8
	75	l 27	l 50	l 300	l 73	l 811	SE. 7·5
	100	l 13	l 40	l 250	l 35	l 676	SE. 6·3
	150	l 3	l 40	l 210	l 8	l 568	SE. 5·3
	200	l 13	l 115	l 170	l 35	l 459	SE. 4·3
	300	l 10	l 55	l 55	l 27	l 149	SE. 1·4
	400	l 1		0	l 3	0	0
Sect. XII, 47–48 .... 41 km., 150 m.	0	l 45	r 25	r 494	l 110	r 1205	NW. 11·2
	25	r 65	r 149	r 469	r 159	r 1144	NW. 10·6
	50	r 54	r 111	r 320	r 132	r 781	NW. 7·3
	75	r 35	r 74	r 209	r 85	r 510	NW. 4·7
	100	r 24	r 135	r 135	r 59	r 329	NW. 3·1
	150	r 30		0	r 73	0	0
Sect. XII, 48–49 .... 75 km., 120 m.	0	l 112	l 165	l 257	l 149	l 342	SE. 3·2
	25	l 20	l 56	l 92	l 27	l 122	SE. 1·1
	50	l 25	l 36	l 36	l 33	l 48	SE. 0·5
	70	l 11		0	l 15	0	0
Sect. XII, 49–50 .... 71 km., 60 m.	0	r 31	r 17	l 262	r 44	l 369	SE. 3·5
	10	r 3	l 118	l 279	r 4	l 393	SE. 3·7
	25	l 160	l 161	l 161	l 225	l 227	SE. 2·2
	40	l 55		0	l 78	0	0
Sect. XIII, 37–38 .... 38 km., 90 m.	0	l 56	l 123	l 340	l 147	l 895	NE. 9·0
	20	l 67	l 129	l 217	l 176	l 571	NE. 5·7
	40	l 62	l 88	l 88	l 163	l 232	NE. 2·3
	60	l 26		0	l 68	0	0
Sect. XIII, 38–39 .... 38 km., 130 m.	0	r 16	r 5	r 65	r 42	r 171	SW. 1·7
	25	l 12	l 23	r 60	l 32	r 158	SW. 1·6
	40	l 19	r 8	r 83	l 50	r 218	SW. 2·2
	50	r 36	r 68	r 75	r 95	r 197	SW. 2·0
	75	r 18	r 7	r 7	r 47	r 18	SW. 0·2
	90	l 9		0	l 24	0	0

Table 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA 10km	u.
Sect. XIII, 39–40 38 km., 115 m.	0	l 45	r 82	r 568	l 118	r 1495	SW. 15·1
	25	r 111	r 168	r 486	r 292	r 1278	SW. 12·9
	40	r 113	r 84	r 318	r 297	r 836	SW. 8·4
	50	r 55	r 142	r 234	r 145	r 616	SW. 6·2
	75	r 58	r 92	r 92	r 153	r 242	SW. 2·4
	90	r 65		0	r 171	0	0
Sect. XIII, 40–41 38 km., 270 m.	0	r 144	r 155	r 344	r 379	r 905	SW. 9·2
	25	l 20	r 33	r 189	l 53	r 497	SW. 5·1
	50	r 46	r 76	r 156	r 121	r 410	SW. 4·2
	75	r 15	r 41	r 80	r 39	r 210	SW. 2·1
	100	r 18	r 39	r 39	r 47	r 103	SW. 1·1
	125	r 13		0	r 34	0	0
Sect. XIII, 41–42 38 km., >400 m.	0	l 5	l 10	r 49	l 13	r 129	SW. 1·3
	25	l 3	l 24	r 59	l 8	r 155	SW. 1·5
	50	l 16	l 10	r 83	l 42	r 218	SW. 2·2
	75	r 8	r 15	r 93	r 21	r 245	SW. 2·5
	100	r 4	r 23	r 78	r 11	r 205	SW. 2·1
	150	r 5	r 30	r 55	r 13	r 145	SW. 1·5
	200	r 7	r 35	r 25	r 18	r 66	SW. 0·7
	300	0	l 10	l 10	0	l 26	NE. 0·3
	400	l 2		0	l 5	0	0
Sect. XIII, 42–43 39 km., >400 m.	0	l 10	l 24	l 1018	l 26	l 2610	NE. 26·9
	25	l 9	l 103	l 994	l 23	l 2549	NE. 26·3
	50	l 73	l 126	l 891	l 187	l 2284	NE. 23·5
	75	l 28	l 80	l 765	l 72	l 1961	NE. 20·2
	100	l 36	l 152	l 685	l 92	l 1756	NE. 18·1
	150	l 25	l 143	l 533	l 64	l 1366	NE. 14·1
	200	l 32	l 245	l 390	l 82	l 1000	NE. 10·3
	300	l 17	l 145	l 145	l 44	l 372	NE. 3·8
	400	l 12		0	l 31	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XIII, 43–44........................ 39 km., >400 m.	0	l 37	l 109	r 323	l 95	r 828	SW. 8·6
	25	l 50	l 68	r 432	l 128	r 1107	SW. 11·5
	50	l 4	l 24	r 500	l 10	r 1282	SW. 13·3
	75	l 15	r 9	r 524	l 38	r 1343	SW. 14·0
	100	r 22	r 95	r 515	r 56	r 1320	SW. 13·7
	150	r 16	r 95	r 420	r 41	r 1077	SW. 11·2
	200	r 22	r 180	r 325	r 56	r 833	SW. 8·7
	300	r 14	r 145	r 145	r 36	r 372	SW. 3·9
	400	r 15		0	r 38	0	0
Sect. XIV, 44–45........................ 83 km., >400 m.	0	r 58	r 118	r 456	r 70	r 549	E. 5·7
	25	r 36	r 75	r 338	r 43	r 407	E. 4·2
	50	r 24	r 43	r 263	r 29	r 317	E. 3·3
	75	r 11	r 4	r 219	r 13	r 264	E. 2·7
	100	l 8	l 25	r 215	l 10	r 259	E. 2·7
	150	l 2	l 5	r 240	l 2	r 289	E. 3·0
	200	0	r 100	r 245	0	r 295	E. 3·0
	300	r 20	r 145	r 145	r 24	r 175	E. 1·8
	400	r 9		0	r 11	0	0
Sect. XIV, 45–46........................ 56 km., >400 m.	0	l 107	l 163	l 138	l 192	l 246	W. 2·5
	25	l 23	r 31	r 25	l 41	r 45	E. 0·5
	50	r 48	r 80	l 6	r 86	l 11	W. 0·1
	75	r 16	r 22	l 86	r 29	l 154	W. 1·6
	100	r 1	r 20	l 108	r 2	l 193	W. 2·0
	150	r 7	r 12	l 128	r 13	l 229	W. 2·3
	200	l 2	l 35	l 140	l 4	l 250	W. 2·6
	300	l 5	l 105	l 105	l 9	l 187	W. 1·9
	400	l 16		0	l 29	0	0
Sect. XIV, 46–47........................ 85 km., 150 m.	0	r 85	r 129	r 72	r 100	r 85	E. 0·9
	25	r 18	l 47	l 57	r 21	l 67	W. 0·7
	50	l 56	l 64	l 10	l 66	l 12	W. 0·1
	75	r 5	r 23	r 54	r 6	r 64	E. 0·6
	100	r 13	r 31	r 31	r 15	r 36	E. 0·4
	125	r 12		0	r 14	0	

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XIV, 47–48........................ 74 km., 170 m.	0	l 114	l 205	l 282	l 154	l 381	W. 4·0
	25	l 50	l 25	l 77	l 68	l 104	W. 1·2
	50	r 30	r 6	l 52	r 41	l 70	W. 0·9
	75	l 26	l 47	l 58	l 35	l 78	W. 0·8
	100	l 11	l 11	l 11	l 15	l 15	W. 0·1
	125	r 2		0	r 3	0	0
Sect. XIV, 48–49........................ 72 km., 180 m.	0	l 26	r 10	l 370	l 36	l 514	W. 5·0
	25	r 34	r 39	l 380	r 47	l 528	W. 5·2
	40	r 18	l 9	l 419	r 25	l 582	W. 5·7
	50	l 36	l 99	l 410	l 50	l 570	W. 5·6
	75	l 43	l 135	l 311	l 60	l 432	W. 4·2
	100	l 65	l 176	l 176	l 90	l 244	W. 2·4
	125	l 76		0	l 106	0	0
Sect. XV, 49–50........................ 35 km., 130 m.	0	r 36	r 59	r 517	r 103	r 1477	SW. 14·5
	25	r 11	r 60	r 458	r 31	r 1309	SW. 12·8
	50	r 37	r 103	r 398	r 106	r 1138	SW. 11·2
	75	r 46	r 138	r 294	r 132	r 840	SW. 8·2
	100	r 64	r 156	r 156	r 183	r 446	SW. 4·4
	125	r 61		0	r 174	0	0
Sect. XV, 50–51........................ 44 km., 180 m.	0	r 26	r 15	r 112	r 59	r 255	SW. 2·5
	25	l 14	l 3	r 97	l 32	r 220	SW. 2·2
	50	r 12	r 39	r 100	r 27	r 227	SW. 2·2
	75	r 19	r 40	r 61	r 43	r 138	SW. 1·4
	100	r 13	r 21	r 21	r 30	r 48	SW. 0·5
	125	r 4		0	r 9	0	0
Sect. XV, 51–52........................ 45 km., 120 m.	0	r 43	r 94	r 74	r 95	r 164	SW. 1·6
	25	r 32	r 16	l 20	r 71	l 44	NE. 0·4
	40	l 11	l 6	l 36	l 24	l 80	NE. 0·8
	50	l 2	l 20	l 30	l 4	l 67	NE. 0·7
	75	l 13	l 10	l 10	l 29	l 22	NE. 0·2
	90	0		0	0	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA₁₀₀km	u.
Sect. XV, 52–53........................ 35 km., 90 m.	0	r 27	r 83	r 163	r 77	r 466	SW. 4·7
	25	r 39	r 52	r 80	r 112	r 229	SW. 2·3
	40	r 30	r 21	r 28	r 86	r 80	SW. 0·8
	50	r 12	r 18	r 7	r 34	r 20	SW. 0·2
	75	r 2	l 11	l 11	r 6	l 31	NE. 0·3
	90	l 17		0	l 49	0	0
Sect. XV, 53–54........................ 41 km., 105 m.	0	l 52	l 106	r 36	l 127	r 89	SW. 0·9
	25	l 33	l 13	r 142	l 81	r 351	SW. 3·5
	50	r 23	r 80	r 155	r 56	r 378	SW. 3·8
	75	r 41	r 75	r 75	r 100	r 183	SW. 1·8
	95	r 34		0	r 83	0	0
Sect. XV, 54–55........................ 35 km., >400 m.	0	l 42	l 19	l 443	l 120	l 1265	NE. 12·8
	25	r 27	r 15	l 424	r 77	l 1211	NE. 12·2
	50	l 15	l 29	l 439	l 43	l 1254	NE. 12·7
	75	l 8	l 20	l 410	l 23	l 1171	NE. 11·8
	100	l 8	l 30	l 390	l 23	l 1114	NE. 11·3
	150	l 4	l 15	l 360	l 11	l 1028	NE. 10·4
	200	l 2	l 150	l 345	l 6	l 986	NE. 10·0
	300	l 28	l 195	l 195	l 80	l 557	NE. 5·6
	400	l 11		0	l 31	0	0
Sect. XV, 55–56........................ 48 km., >400 m.	0	l 56	l 66	l 336	l 116	l 700	NE. 7·1
	25	r 3	r 8	l 270	r 6	l 563	NE. 5·7
	50	r 3	l 5	l 278	r 6	l 579	NE. 5·9
	100	l 5	l 40	l 273	l 10	l 569	NE. 5·8
	150	l 11	l 68	l 233	l 23	l 485	NE. 4·9
	200	l 16	l 75	l 165	l 33	l 343	NE. 3·5
	300	r 1	l 90	l 90	r 2	l 187	NE. 1·9
	400	l 19		0	l 40	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XVI, 56–57. 77 km., >400 m.	0	r 89		r 711	r 116	r 924	E. 9·4
			r 86				
	25	l 20		r 625	l 26	r 812	E. 8·2
			l 48				
	50	l 18		r 673	l 23	r 874	E. 8·9
			l 15				
	100	r 12		r 688	r 16	r 894	E. 9·1
			r 70				
	150	r 16		r 618	r 21	r 803	E. 8·2
			r 113				
	200	r 29		r 505	r 38	r 656	E. 6·7
			r 255				
	300	r 22		r 250	r 29	r 325	E. 3·3
			r 250				
	400	r 28		0	r 36	0	0
Sect. XVI, 57–58. 47 km., >400 m.	0	r 21		l 108	r 45	l 230	W. 2·3
			r 30				
	25	r 3		l 138	r 6	l 293	W. 2·9
			r 13				
	50	r 7		l 151	r 15	l 321	W. 3·2
			l 31				
	75	l 32		l 120	l 68	l 255	W. 2·6
			l 49				
	100	l 7		l 71	l 15	l 151	W. 1·5
			l 45				
	150	l 11		l 26	l 23	l 55	W. 0·6
			l 26				
	175	l 10		0	l 21	0	0
Sect. XVI, 58–59. 47 km., 70 m.	0	r 16		l 139	r 34	l 296	W. 3·0
			l 20				
	15	l 42		l 119	l 89	l 253	W. 2·5
			l 59				
	30	l 36		l 60	l 77	l 128	W. 1·3
			l 60				
	45	l 44		0	l 94	0	0
Sect. XVI, 59–60. 56 km., 60 m.	0	l 26		r 51	l 47	r 91	E. 0·9
			l 2				
	15	r 24		r 53	r 43	r 94	E. 0·9
			r 28				
	30	r 13		r 25	r 23	r 44	E. 0·4
			r 25				
	45	r 20		0	r 36	0	0
Sect. XVI, 60–62. 53 km., 90 m.	0	l 23		l 287	l 43	l 542	W. 5·3
			l 109				
	25	l 64		l 178	l 121	l 336	W. 3·3
			l 134				
	50	l 43		l 44	l 81	l 83	W. 0·8
			l 44				
	60	l 45		0	l 85	0	0
Sect. XVI, 62–63. 17 km., 50 m.	0	l 2		r 150	l 12	r 882	E. 8·6
			r 64				
	25	r 53		r 86	r 312	r 506	E. 4·9
			r 86				
	50	r 16		0	r 94	0	0

Table 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	a.	0·1 A.	0·1 ΣA.	$a_{100km.}$	ΣA $_{10km}$	u.
Sect. XVI, 63-64........................ 38 km., 150 m.	0	l 61		l 318	l 160	l 837	W. 8·1
			l 163				
	25	l 69		l 155	l 181	l 408	W. 4·0
			l 155				
	50	l 55		0	l 145	0	0
Sect. XVI, 64-65........................ 24 km., 130 m.	0	l 39		r 66	l 163	r 277	E. 2·7
			l 5				
	25	r 35		r 71	r 146	r 296	E. 2·9
			r 96				
	50	r 42		l 25	r 175	l 104	W. 1·0
			r 26				
	75	l 21		l 51	l 88	l 212	W. 2·0
			l 51				
	100	l 20		0	l 83	0	0
Sect. XVII, 65-66........................ 30 km., 130 m.	0	r 61		l 189	r 203	l 630	NE. 6·0
			r 40				
	10	r 19		l 229	r 63	l 763	NE. 7·3
			l 67				
	25	l 108		l 162	l 360	l 540	NE. 5·2
			l 159				
	50	l 19		l 3	l 63	l 10	NE. 0·1
			l 3				
	60	r 13		0	r 43	0	0
Sect. XVII, 66-67........................ 67 km., 90 m.	0	r 33		r 365	r 49	r 545	SW. 5·3
			r 31				
	10	r 30		r 334	r 45	r 499	SW. 4·8
			r 108				
	25	r 115		r 225	r 171	r 336	SW. 3·3
			r 196				
	50	r 42		r 29	r 63	r 43	SW. 0·4
			r 29				
	60	r 15		0	r 22	0	0
Sect. XVII, 67-68........................ 57 km., 140 m.	0	r 26		r 255	r 46	r 447	SW. 4·4
			r 35				
	10	r 43		r 220	r 75	r 386	SW. 3·8
			r 102				
	25	r 93		r 118	r 163	r 207	SW. 2·0
			r 118				
	50	r 1		0	r 2	0	0
Sect. XVII, 68-69........................ 44 km., 70 m.	0	l 20		l 167	l 45	l 379	NE. 3·7
			l 28				
	10	l 37		l 139	l 84	l 316	NE. 3·1
			l 89				
	25	l 82		l 50	l 186	l 114	NE. 1·1
			l 55				
	40	r 9		r 5	r 20	r 11	SW. 0·1
			r 5				
	50	r 1		0	r 2	0	0
Sect. XVII, 69-70........................ 49 km., 130 m.	0	r 34		r 277	r 69	r 565	SW. 5·5
			r 133				
	25	r 72		r 144	r 147	r 294	SW. 2·9
			r 144				
	50	r 43		0	r 88	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	u.
Sect. XVII, 70–71, 29 km., >400 m.	0	0		l 45	0	l 155	NE. 1·5
			l 21				
	25	l 17		l 24	l 58	l 82	NE. 0·8
			l 30				
	50	l 7		r 6	l 24	r 21	SW. 0·2
			l 3				
	75	r 5		r 9	r 17	r 31	SW. 0·3
			r 9				
	100	r 2		0	r 7	0	0
Sect. XVII, 71–72, 21 km., >400 m.	0	l 49		r 21	l 233	r 100	SW. 1·0
			l 32				
	25	r 24		r 53	r 114	r 250	SW. 2·5
			r 53				
	50	r 18		0	r 86	0	0
			r 16				
	75	l 5		l 16	l 24	l 76	NE. 0·8
			l 16				
	100	l 8		0	l 38	0	0
Sect. XVII, 72–73, 19 km., >400 m.	0	r 5		l 3	r 26	l 16	NE. 0·2
			l 16				
	25	l 18		r 13	l 95	r 68	SW. 0·7
			l 15				
	50	r 6		r 28	r 32	r 147	SW. 1·5
			r 17				
	75	r 7		r 11	r 37	r 58	SW. 0·6
			r 11				
	100	r 2		0	r 11	0	0
Sect. XVII, 73–74, 20 km., >400 m.	0	r 6		r 11	r 30	r 55	SW. 0·5
			r 35				
	5	r 22		l 24	r 110	l 120	NE. 1·2
			r 21				
	50	l 5		l 45	l 25	l 225	NE. 2·2
			l 17				
	75	l 9		l 28	l 45	l 140	NE. 1·4
			l 28				
	100	l 13		0	l 65	0	0
Sect. XVII, 74–75, 39 km., >400 m.	0	r 48		l 238	r 123	l 610	NE. 6·1
			r 21				
	25	l 31		l 259	l 79	l 664	NE. 6·6
			l 135				
	50	l 77		l 124	l 197	l 318	NE. 3·2
			l 109				
	75	l 10		l 15	l 26	l 38	NE. 0·4
			l 15				
	100	l 2		0	l 5	0	0
			l 20				
	150	l 6		r 20	l 15	r 51	SW. 0·5
			l 10				
	200	r 2		r 30	r 5	r 77	SW. 0·8
			r 20				
	300	r 2		r 10	r 5	r 26	SW. 0·3
			r 10				
	400	0		0	0		0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. XVIII, 75-76........................ 62 km., >400 m.	0	*l* 126		*r* 379	*l* 203	*r* 611	SE. 6·1
			l 255				
	25	*l* 78		*r* 634	*l* 126	*r*1024	SE. 10·2
			l 29				
	50	*r* 55		*r* 663	*r* 89	*r*1069	SE. 10·6
			r 64				
	75	*l* 4		*r* 599	*l* 6	*r* 966	SE. 9·6
			r 1				
	100	*r* 5		*r* 598	*r* 8	*r* 964	SE. 9·6
			r 60				
	150	*r* 19		*r* 538	*r* 31	*r* 867	SE. 8·6
			r 113				
	200	*r* 26		*r* 425	*r* 42	*r* 685	SE. 6·8
			r 240				
	300	*r* 22		*r* 185	*r* 35	*r* 298	SE. 3·0
			r 185				
	400	*r* 15		0	*r* 24	0	0
Sect. XVIII, 76-77........................ 63 km., >400 m.	0	*r* 28		*r* 277	*r* 45	*r* 440	SE. 4·3
			r 164				
	25	*r* 103		*r* 113	*r* 164	*r* 180	SE. 1·8
			r 151				
	50	*r* 18		*l* 38	*r* 29	*l* 60	NW. 0·6
			r 35				
	75	*r* 10		*l* 73	*r* 16	*l* 116	NW. 1·1
			r 10				
	100	*l* 2		*l* 83	*l* 3	*l* 132	NW. 1·3
			l 5				
	150	0		*l* 78	0	*l* 124	NW. 1·2
			l 8				
	200	*l* 3		*l* 70	*l* 5	*l* 111	NW. 1·1
			l 35				
	300	*l* 4		*l* 35	*l* 6	*l* 56	NW. 0·6
			l 35				
	400	*l* 3		0	*l* 5	0	0
Sect. XVIII, 77-78........................ 28 km., >400 m.	0	*r* 80		*r* 313	*r* 286	*r*1117	SE. 11·0
			r 238				
	50	*r* 15		*r* 75	*r* 54	*r* 268	SE. 2·6
			r 34				
	75	*r* 12		*r* 41	*r* 43	*r* 146	SE. 1·4
			r 41				
	100	*r* 21		0	*r* 75	0	0
Sect. XVIII, 78-79........................ 34 km., >400 m.	0	*r* 50		*l* 62	*r* 147	*l* 182	NW. 1·8
			r 30				
	50	*l* 38		*l* 92	*l* 112	*l* 271	NW. 2·6
			r 63				
	75	*l* 12		*l* 29	*l* 35	*l* 85	NW. 0·8
			l 29				
	100	*l* 11		0	*l* 32	0	0
Sect. XIX, 79-80........................ 59 km., 250 m.	0	*l* 20		*l* 329	*l* 34	*l* 558	SW. 5·4
			l 31				
	10	*l* 42		*l* 298	*l* 71	*l* 505	SW. 4·9
			l 59				
	25	*l* 36		*l* 239	*l* 61	*l* 405	SW. 3·9
			l 31				
	50	*r* 11		*l* 208	*r* 19	*l* 353	SW. 3·4
			r 8				
	75	*l* 5		*l* 216	*l* 8	*l* 366	SW. 3·6
			l 38				
	100	*l* 26		*l* 178	*l* 44	*l* 302	SW. 2·9
			l 178				
	150	*l* 45		0	*l* 76	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a*.	0·1 A.	0·1 ΣA.	$a_{100km.}$	ΣA $_{10km}$	*u*.
Sect. XIX, 80–81........................ 62 km., 65 m.	0	*r* 26		*r* 121	*r* 42	*r* 195	NE. 1·9
			r 23				
	10	*r* 19		*r* 98	*r* 31	*r* 158	NE. 1·5
			r 54				
	25	*r* 53		*r* 44	*r* 85	*r* 97	NE. 0·9
			r 50				
	40	*r* 14		*l* 6	*r* 23	*l* 10	SW. 0·1
			l 6				
	54	*l* 22		0	*l* 35	0	0
Sect. XIX, 81–82........................ 44 km., 60 m.	0	*l* 5		*l* 140	*l* 11	*l* 318	SW. 3·0
			l 12				
	10	*l* 19		*l* 128	*l* 43	*l* 291	SW. 2·8
			l 47				
	25	*l* 43		*l* 81	*l* 98	*l* 184	SW. 1·7
			l 66				
	40	*l* 45		*l* 15	*l* 102	*l* 34	SW. 0·3
			l 15				
	50	*r* 16		0	*r* 36	0	0
Sect. XIX, 82–83........................ 41 km., 140 m.	0	*l* 9		*l* 99	*l* 22	*l* 241	SW. 2·3
			l 48				
	25	*l* 29		*l* 51	*l* 71	*l* 124	SW. 1·2
			l 51				
	50	*l* 12		0	*l* 29	0	0
Sect. XX, 83–84........................ 51 km., 64 m.	0	*r* 15		*r* 118	*r* 29	*r* 231	NW. 2·2
			r 57				
	25	*r* 30		*r* 61	*r* 59	*r* 120	NW. 1·1
			r 61				
	50	*r* 19		0	*r* 37	0	0
Sect. XX, 84–85........................ 49 km., 60 m.	0	*l* 114		*l* 178	*l* 233	*l* 363	SE. 3·4
			l 144				
	20	*l* 30		*l* 34	*l* 61	*l* 69	SE. 0·7
			l 28				
	40	*r* 2		*l* 6	*r* 4	*l* 12	SE. 0·1
			l 6				
	50	*l* 14		0	*l* 29	0	0
Sect. XX, 85–86........................ 44 km., >400 m.	0	*l* 2		*r* 155	*l* 5	*r* 352	NW. 3·3
			r 61				
	25	*r* 51		*r* 94	*r* 116	*r* 213	NW. 2·0
			r 80				
	50	*r* 13		*r* 14	*r* 30	*r* 32	NW. 0·3
			r 36				
	75	*r* 16		*l* 22	*r* 36	*l* 50	SE. 0·5
			r 15				
	100	*l* 4		*l* 37	*l* 9	*l* 84	SE. 0·8
			r 5				
	150	*r* 6		*l* 42	*r* 14	*l* 95	SE. 0·9
			r 3				
	200	*l* 5		*l* 45	*l* 11	*l* 102	SE. 1·0
			l 35				
	300	*l* 2		*l* 10	*l* 5	*l* 23	SE. 0·2
			l 10				
	400	0		0	0	0	0

Table 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. XX, 86–87 .... 37 km., >400 m.	0	0		*l* 40	0	*l* 108	SE. 1·0
			r 4				
	25	*r* 3		*l* 44	*r* 8	*l* 119	SE. 1·1
			r 10				
	50	*r* 5		*l* 54	*r* 14	*l* 146	SE. 1·4
			l 1				
	75	*l* 6		*l* 53	*l* 16	*l* 143	SE. 1·4
			l 8				
	100	0		*l* 45	0	*l* 122	SE. 1·2
			l 25				
	150	*l* 10		*l* 20	*l* 27	*l* 54	SE. 0·5
			l 25				
	200	0		*r* 5	0	*r* 14	NW. 0·1
			r 5				
	300	*r* 1		0	*r* 3	0	0
Sect. XX, 87–88 .... 51 km.. 125 m.	0	*l* 66		*l* 800	*l* 129	*l* 1569	SE. 15·1
			l 159				
	25	*l* 61		*l* 641	*l* 120	*l* 1257	SE. 12·1
			l 173				
	50	*l* 78		*l* 468	*l* 153	*l* 917	SE. 8·8
			l 192				
	75	*l* 75		*l* 276	*l* 147	*l* 541	SE. 5·2
			l 165				
	100	*l* 57		*l* 111	*l* 112	*l* 218	SE. 2·1
			l 111				
	125	*l* 32		0	*l* 63	0	0
Sect. XX, 88–89 .... 43 km., 125 m.	0	*r* 17		*l* 332	*r* 40	*l* 772	SE. 7·4
			l 94				
	25	*l* 92		*l* 238	*l* 214	*l* 554	SE. 5·3
			l 104				
	50	*r* 9		*l* 134	*r* 21	*l* 312	SE. 3·0
			r 10				
	75	*l* 1		*l* 144	*l* 2	*l* 335	SE. 3·2
			l 36				
	100	*l* 28		*l* 108	*l* 65	*l* 251	SE. 2·4
			l 108				
	125	*l* 58		0	*l* 135	0	0

TABLE 6.—The amount of solenoids per 10 km., equivalent to a velocity of the current of 1 cm/sec., at different latitudes.

ϕ	0	1	2	3	4	5	6	7	8	9
0	0	3	5	8	10	13	15	18	20	23
10	25	28	30	33	35	38	40	43	45	48
20	50	52	55	57	59	62	64	66	68	71
30	73	75	77	79	82	84	86	88	90	92
40	94	96	98	100	101	103	105	107	108	110
50	112	113	115	116	118	119	121	122	124	125
60	126	128	129	130	131	132	133	134	135	136
70	137	138	139	139	140	141	142	142	143	143
80	144	144	144	145	145	145	145	146	146	146

TABLE 7.—Correction in cm. of level of water under atmospherical pressure.

(*a*) MILLIBAR.

m.bar.	0	1	2	3	4	5	6	7	8	9
940	−60	−59	−58	−57	−56	−55	−54	−53	−52	−51
950	−50	−49	−48	−47	−46	−45	−44	−43	−42	−41
960	−40	−39	−38	−37	−36	−35	−34	−33	−32	−31
970	−30	−29	−28	−27	−26	−25	−24	−23	−22	−21
980	−20	−19	−18	−17	−16	−15	−14	−13	−12	−11
990	−10	− 9	− 8	− 7	− 6	− 5	− 4	− 3	− 2	− 1
1000	0	1	2	3	4	5	6	7	8	9
1010	10	11	12	13	14	15	16	17	18	19
1020	20	21	22	23	24	25	26	27	28	29
1030	30	31	32	33	34	35	36	37	38	39
1040	40	41	42	43	44	45	46	47	48	49

TABLE 7.—Correction in cm. of level of water under atmospherical pressure—*Concluded.*

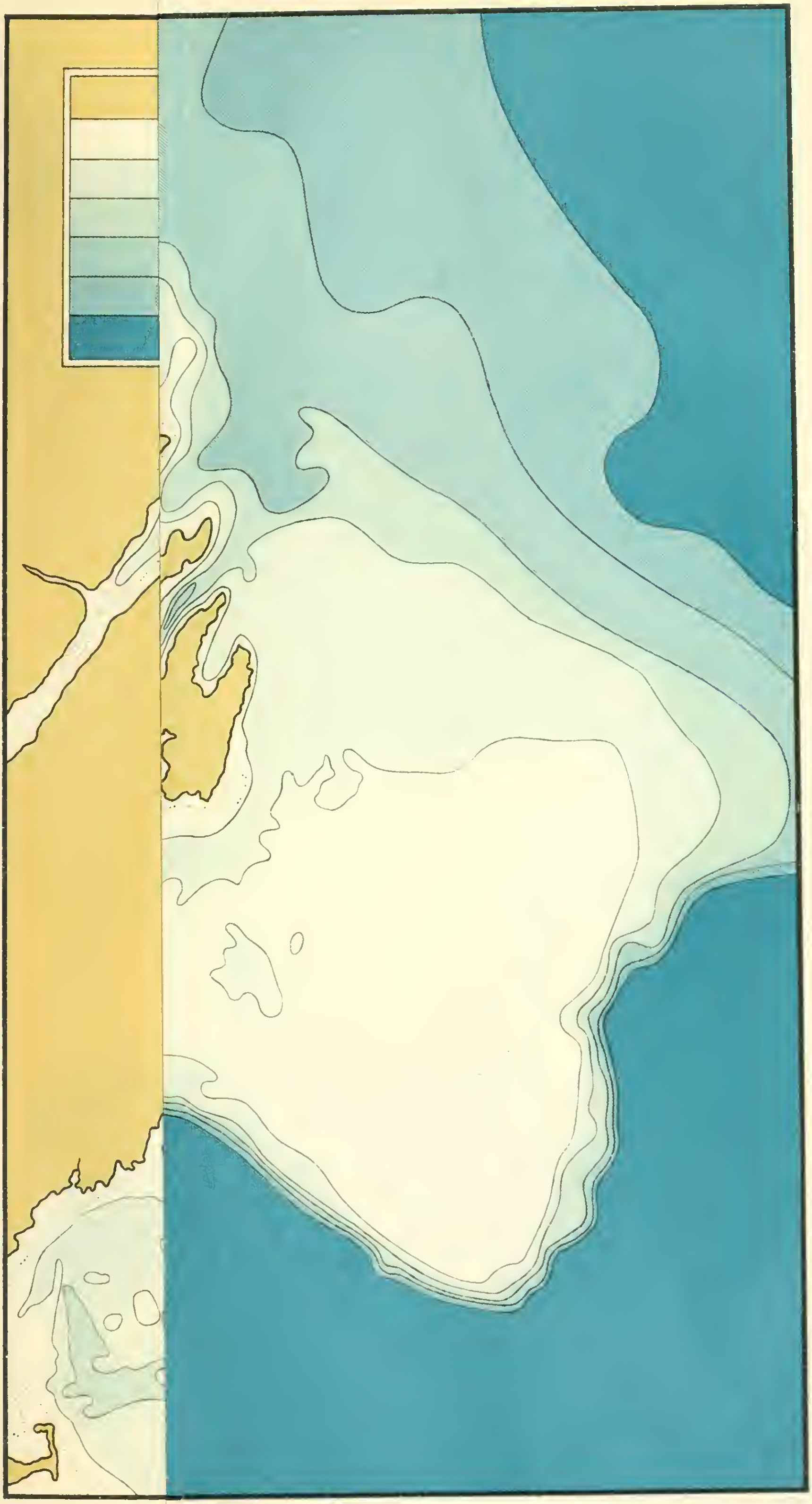
(*b*) MILLIMETER Hg.

mm.	0	1	2	3	4	5	6	7	8	9
700	−66	−65	−64	−62	−61	−60	−58	−57	−56	−54
710	−53	−52	−50	−49	−48	−46	−45	−44	−42	−41
720	−40	−38	−37	−36	−34	−33	−32	−31	−29	−28
730	−27	−25	−24	−21	−25	−21	−19	−17	−16	−15
740	−13	−12	−11	− 9	− 8	− 7	− 5	− 4	− 3	− 1
750	0	1	3	4	5	7	8	9	10	12
760	13	14	16	17	18	20	21	22	24	25
770	26	28	29	30	32	33	34	36	37	38
780	40	41	42	44	45	46	48	49	50	51
790	53	54	55	57	58	59	61	62	63	65

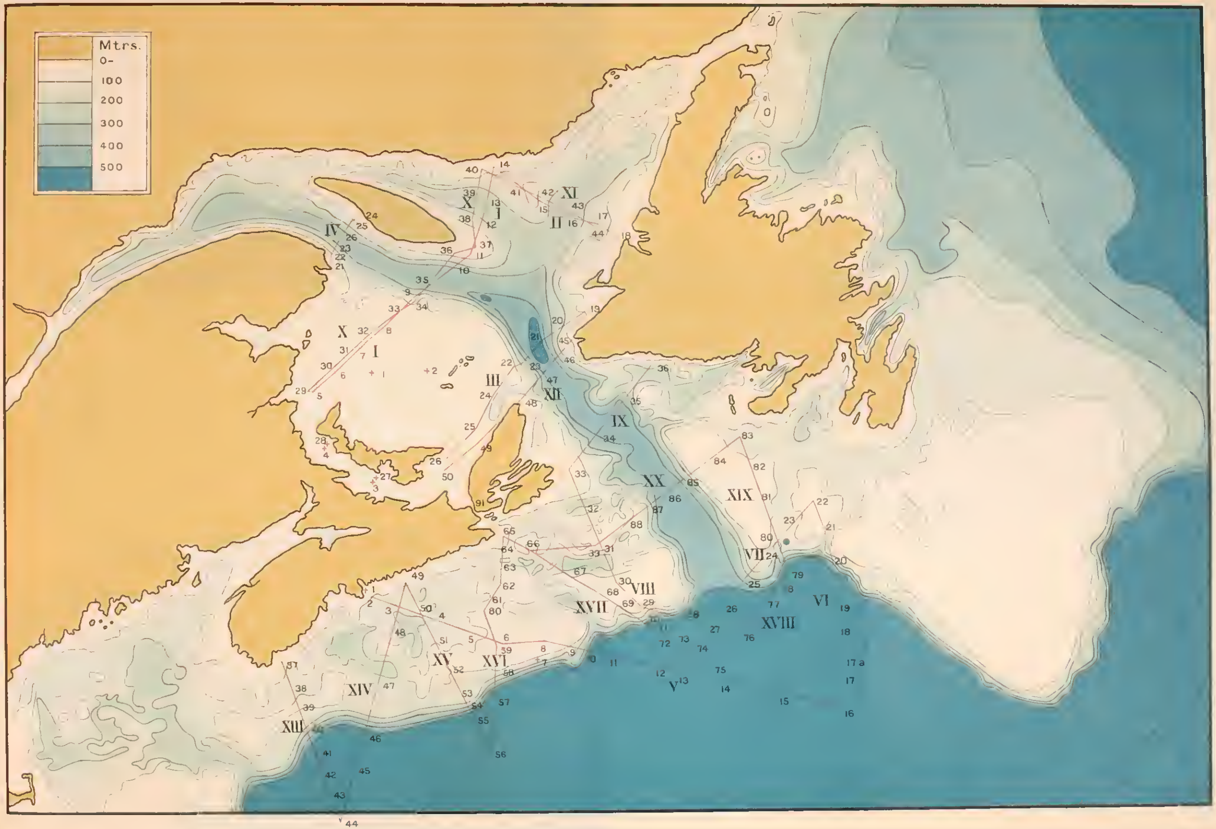
(*c*) $^1/_{10}$ OF AN INCH Hg.

in	0	1	2	3	4	5	6	7	8	9
28	−51	−48	−45	−41	−38	−35	−31	−28	−25	−21
29	−18	−14	−11	− 8	− 4	− 1	2	6	9	12
30	16	19	22	26	29	33	36	39	43	46

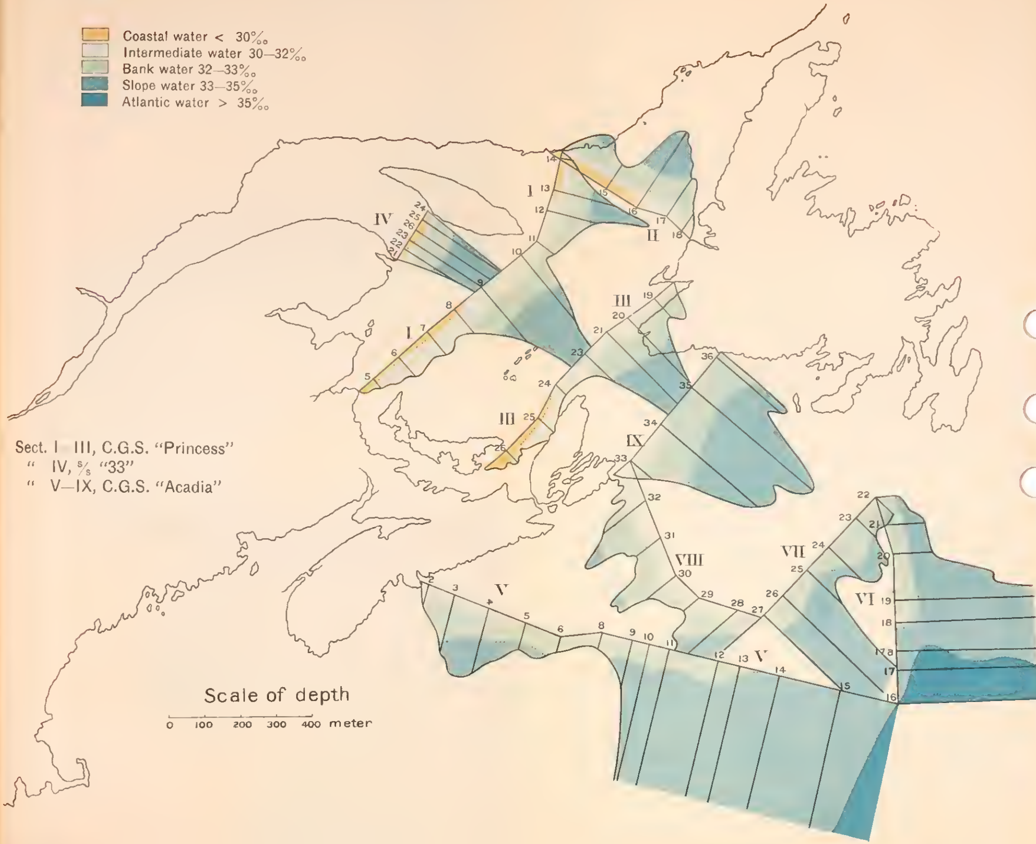
PL. 1



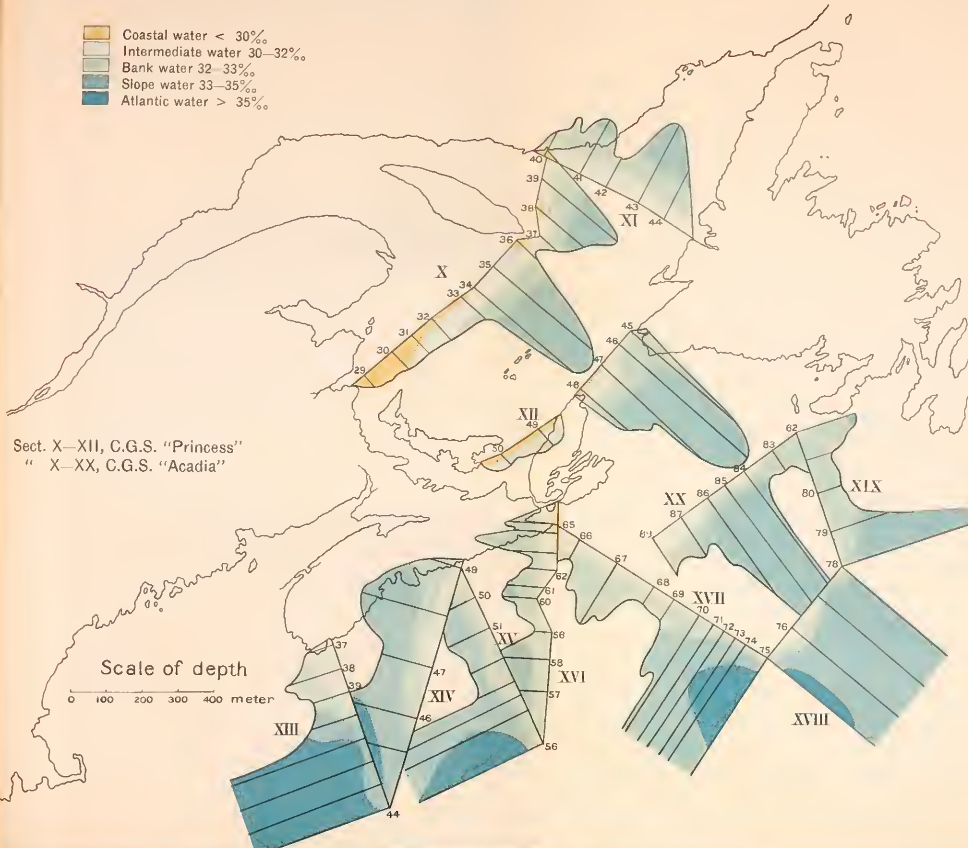
PL. 1



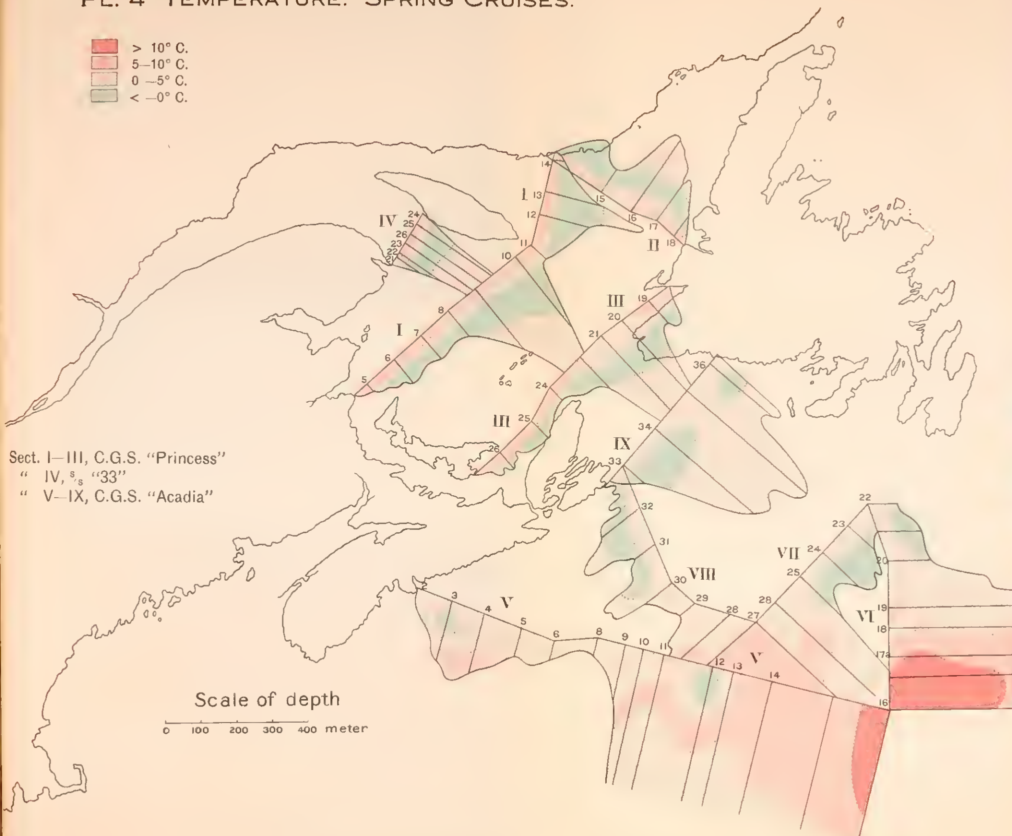
PL. 2 SALINITY. SPRING CRUISES.



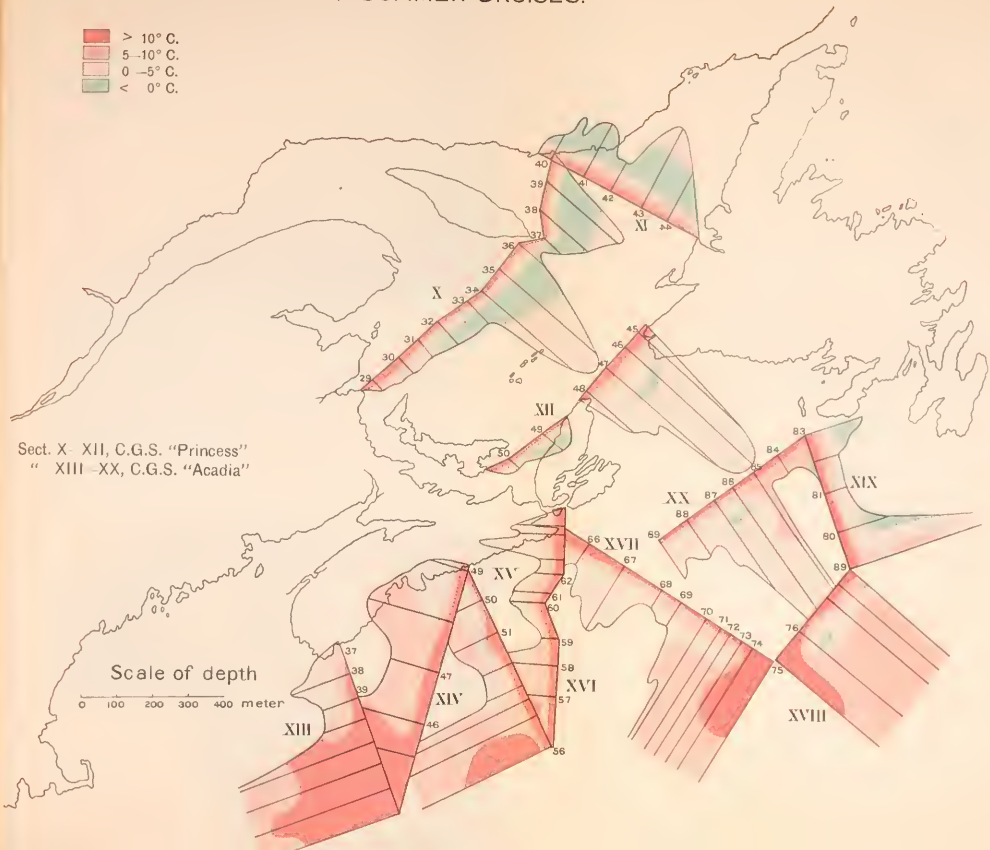
PL. 3 SALINITY. SUMMER CRUISES.



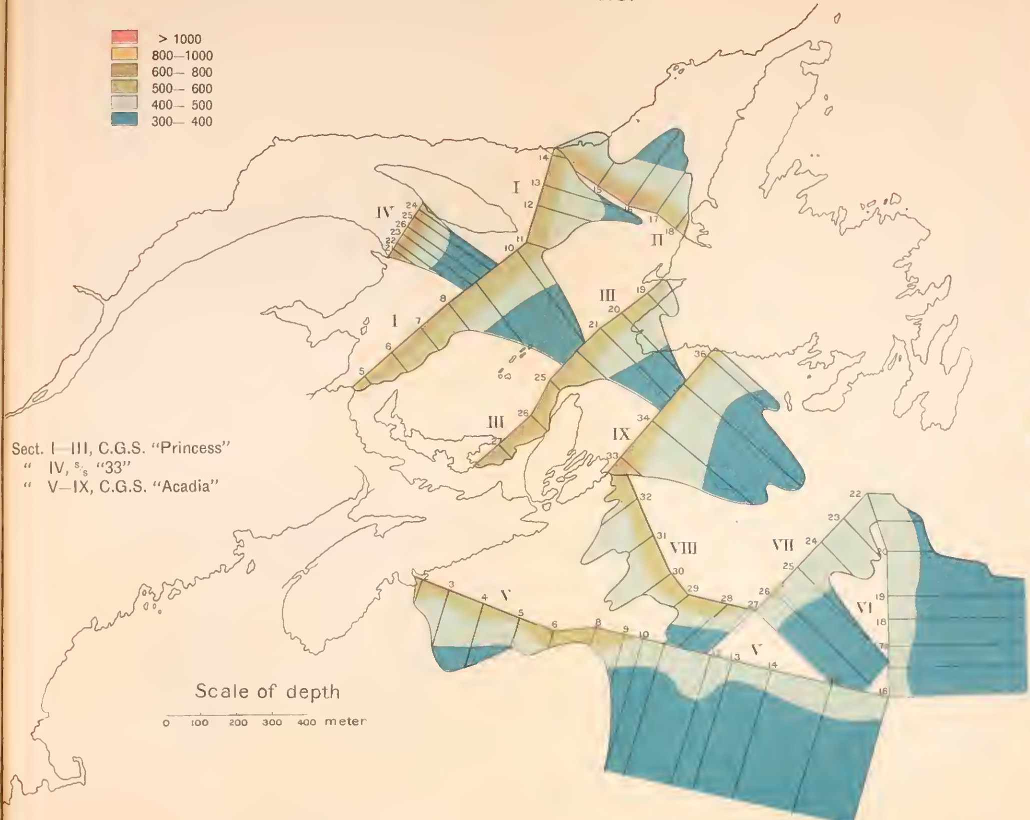
PL. 4 TEMPERATURE. SPRING CRUISES.



PL. 5 TEMPERATURE. SUMMER CRUISES.



PL. 6 SPECIFIC VOLUME. SPRING CRUISES.

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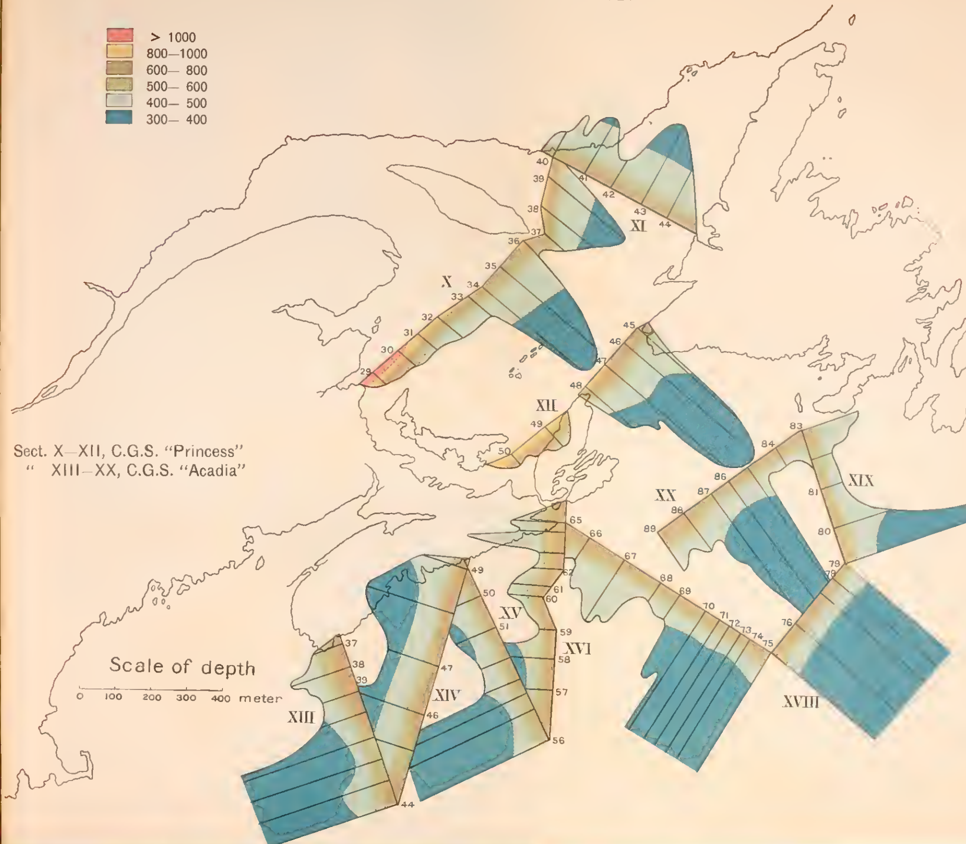
500

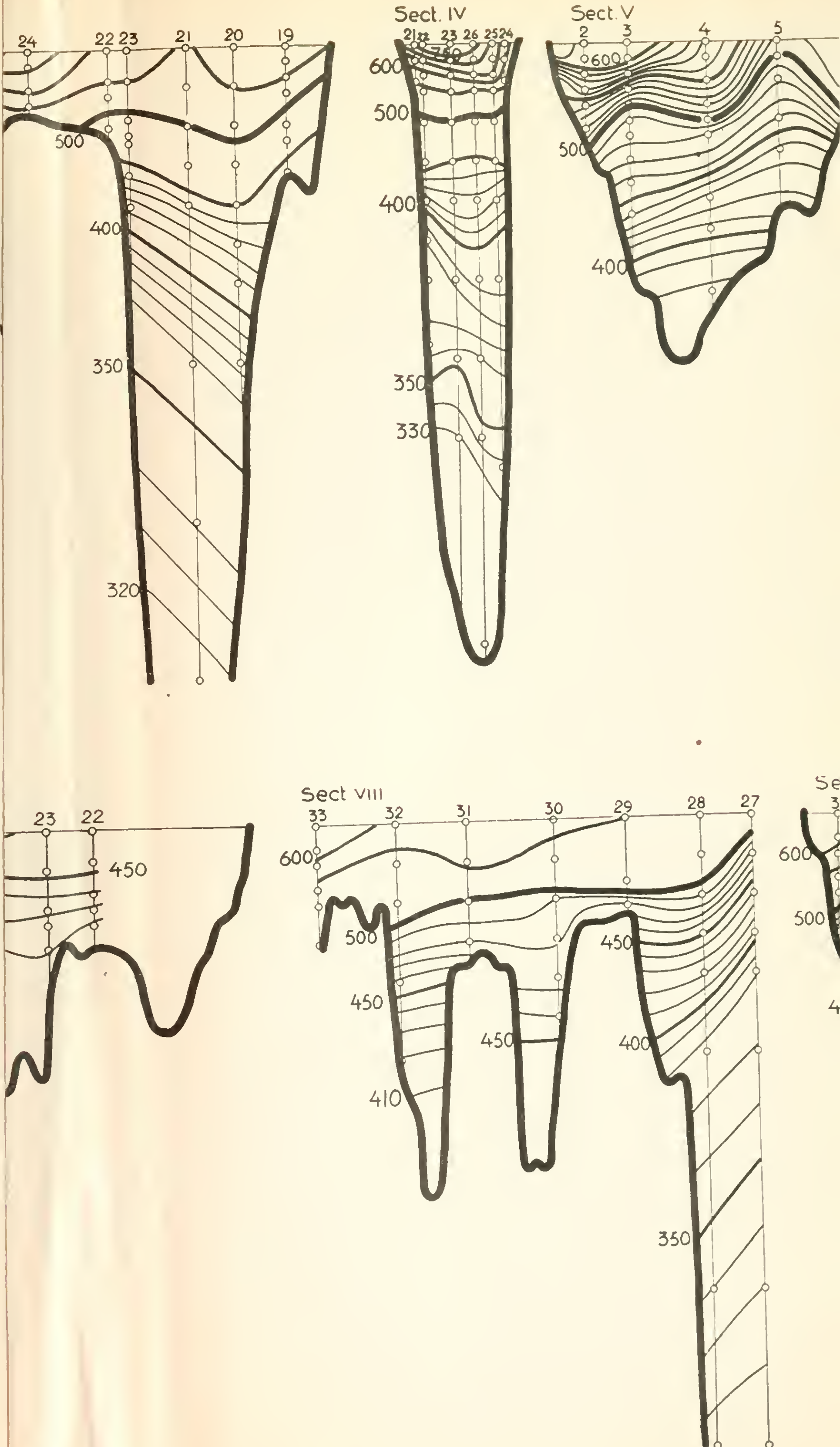
PL. 7 SPECIFIC VOLUME. SUMMER CRUISES.



Pl. VI

Speci

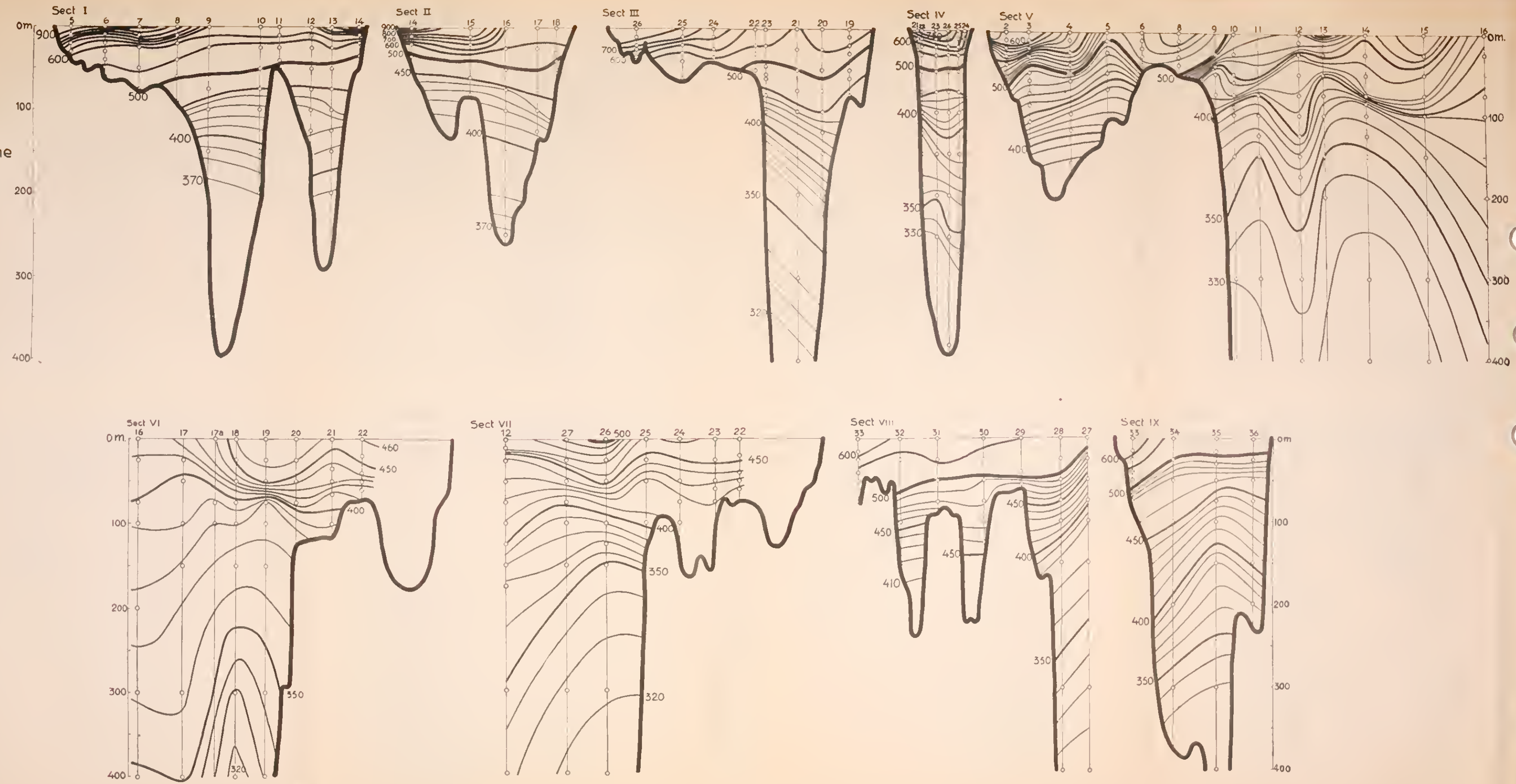
[Sprin



Pl. VIII

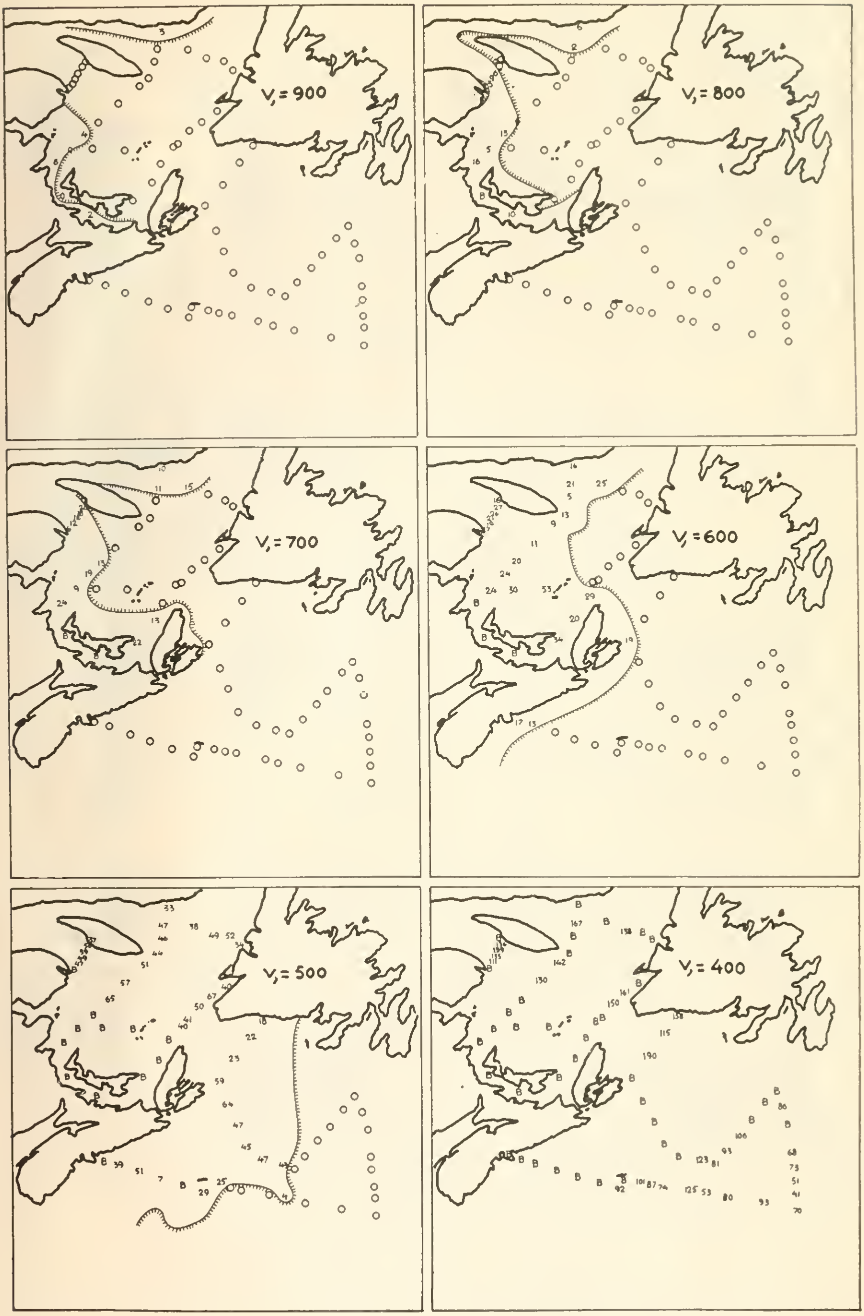
Specific volume

[Spring cruises]



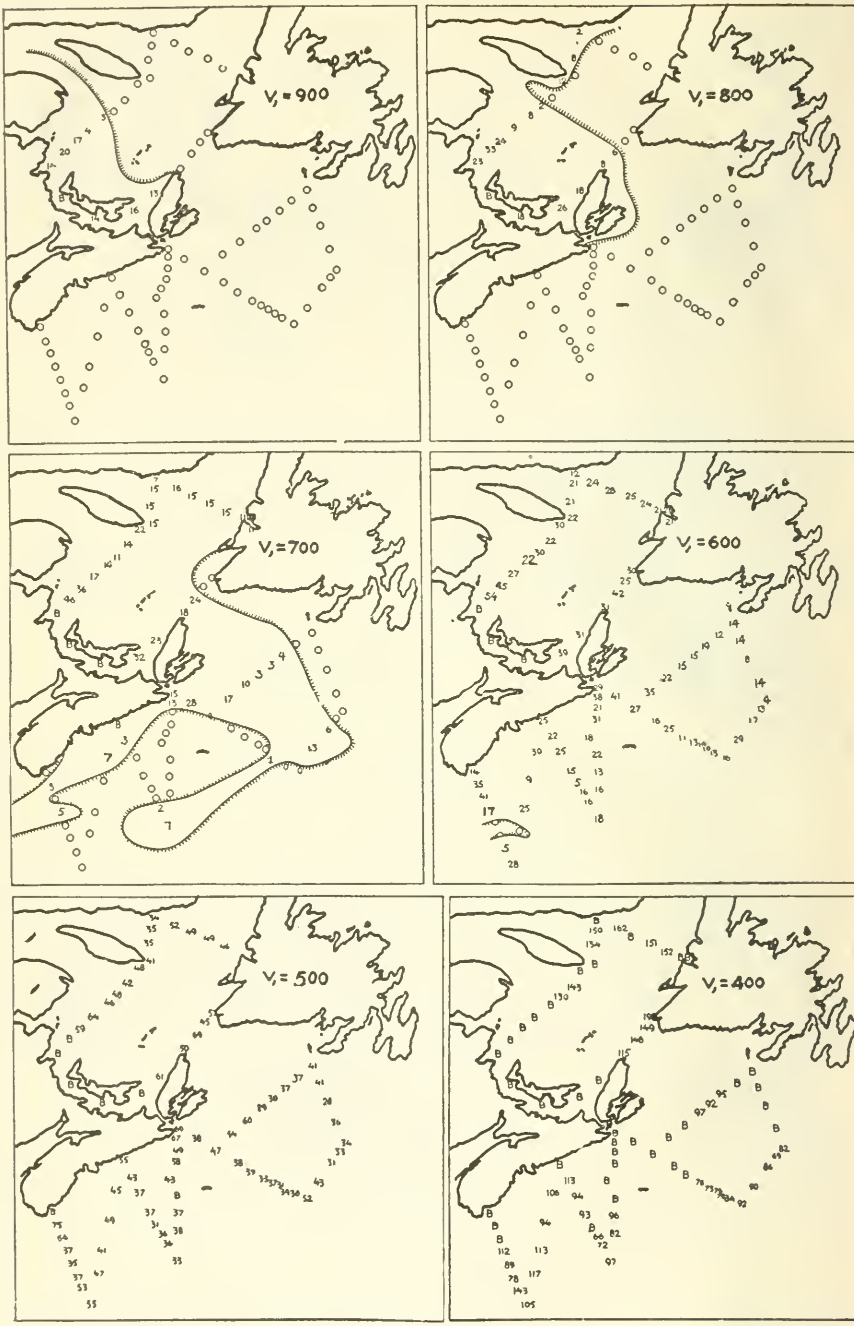
Pl. X

Depth in metres of the Isosteric Surfaces
Spring Cruises



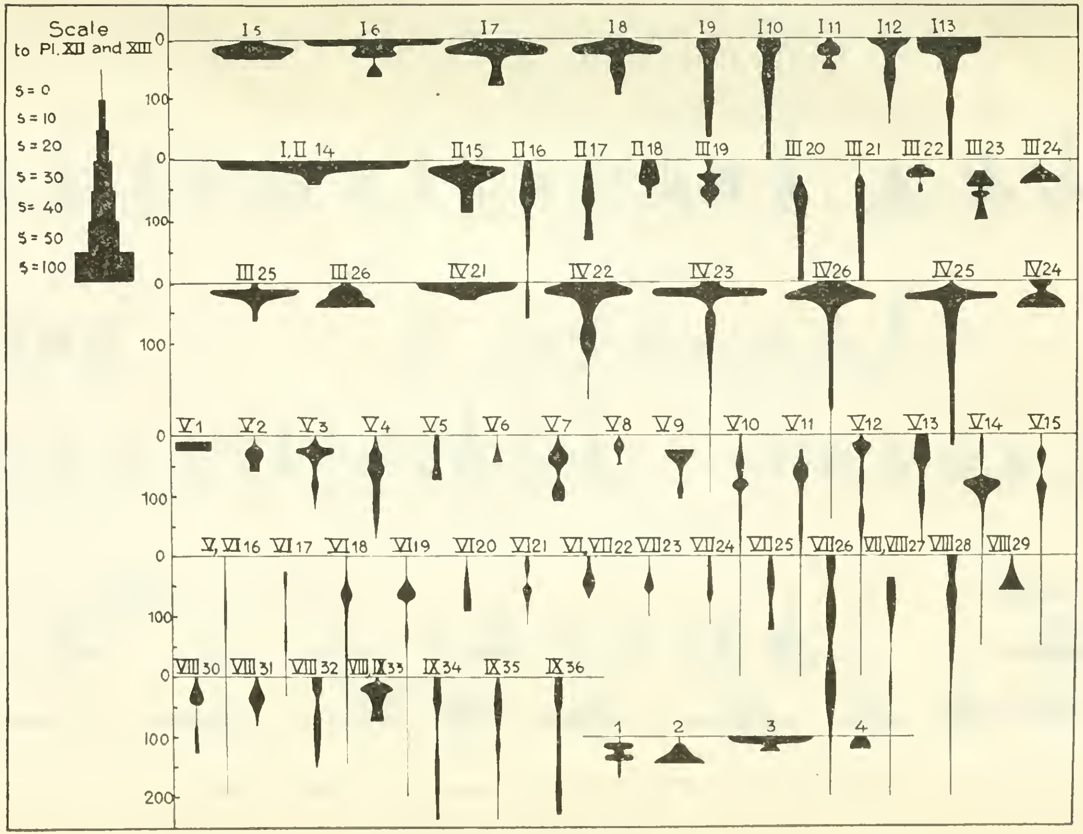
Pl. XI

Depth in metres of the Isosteric Surfaces
Summer Cruises



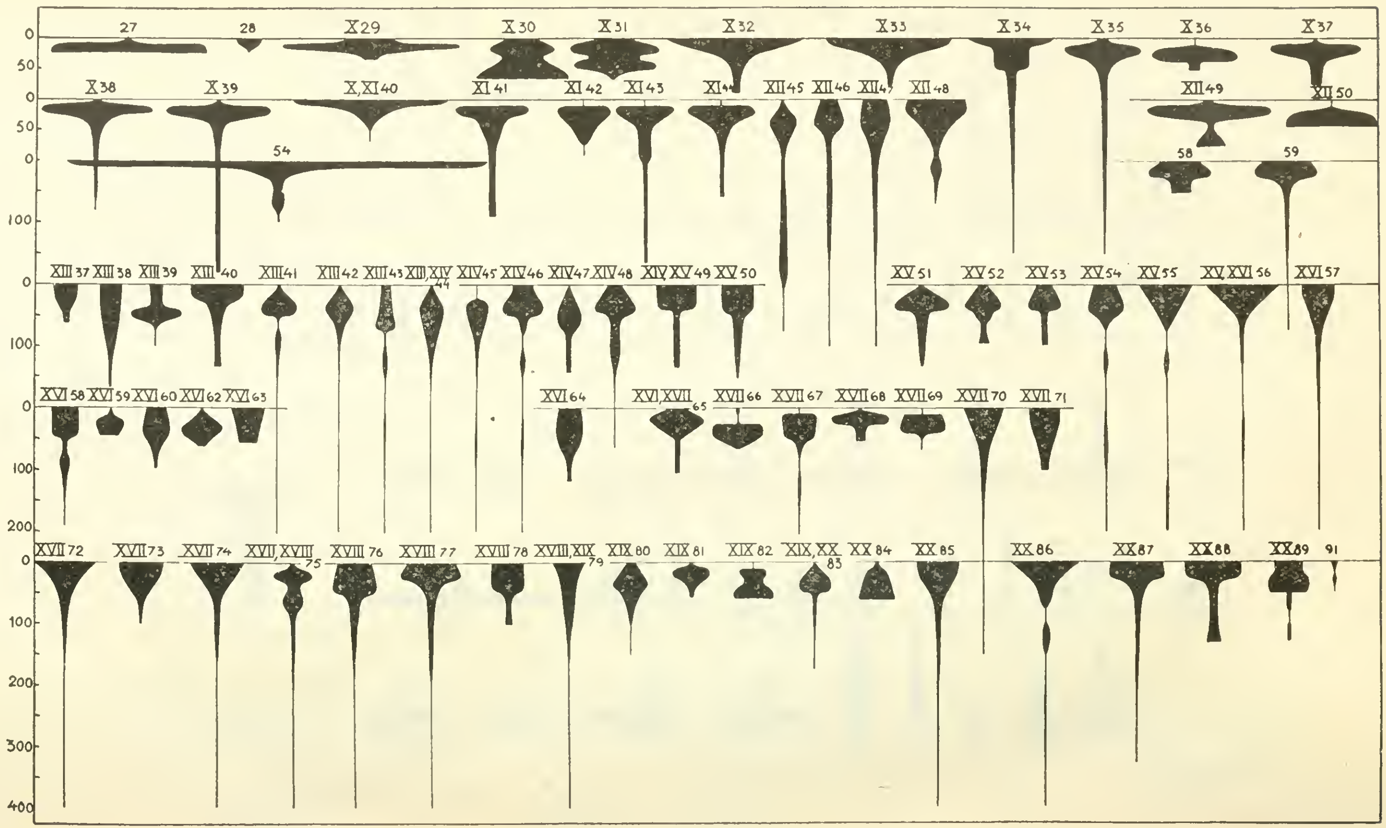
Pl. XII

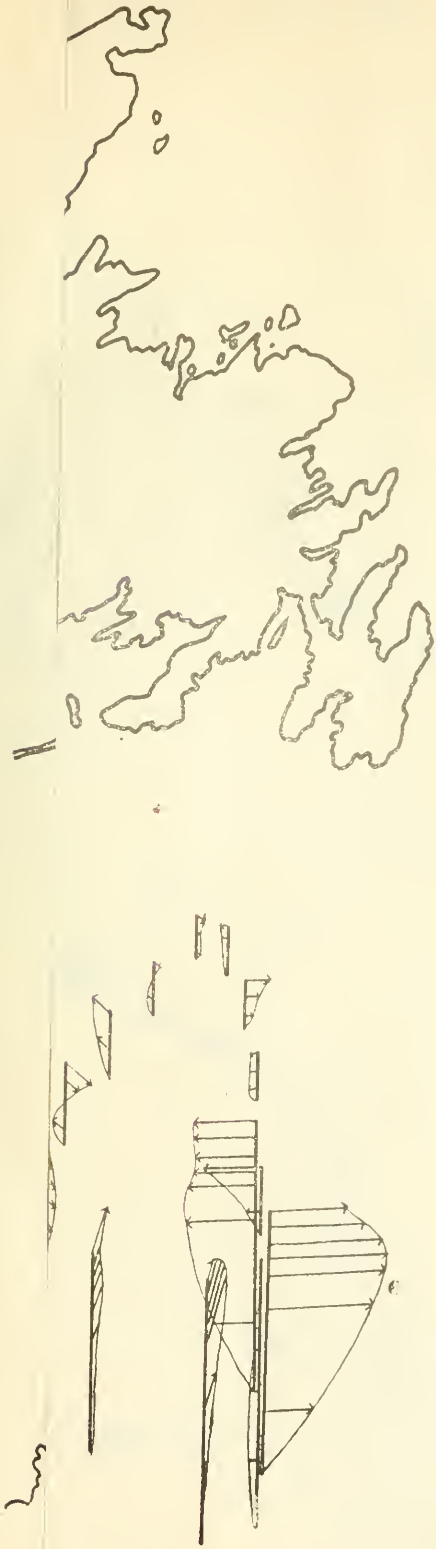
Stability conditions
in the Canadian Atlantic waters during the spring 1915



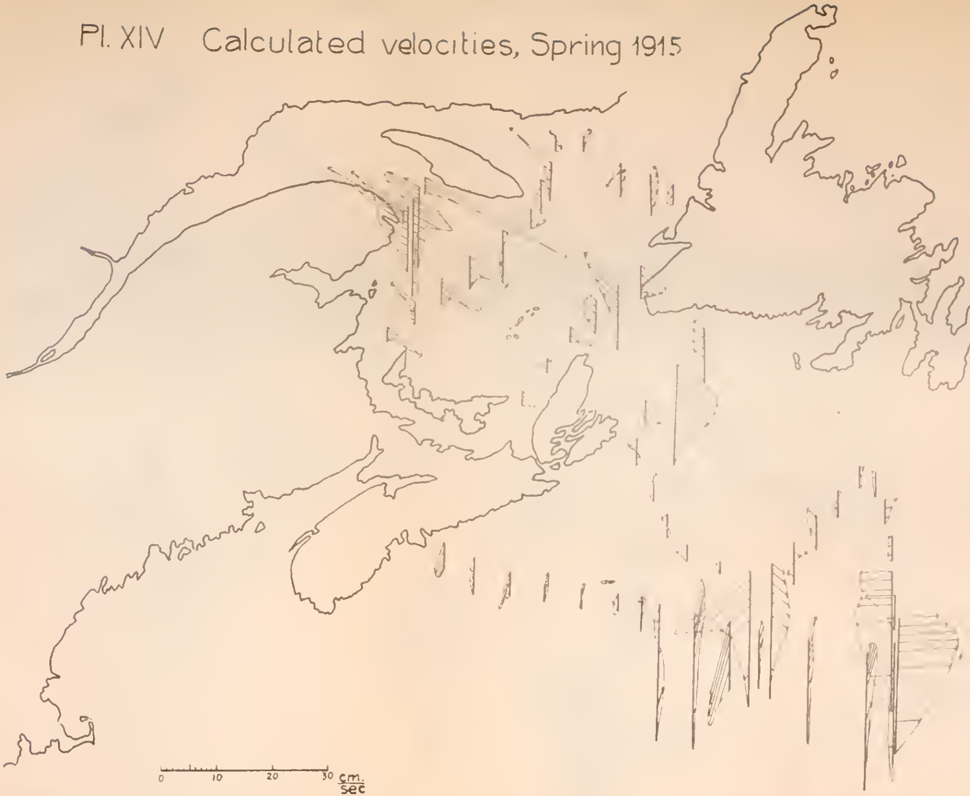
Pl. XIII

Stability conditions
in the Canadian Atlantic waters during the summer 1915





Pl. XIV Calculated velocities, Spring 1915



Pl XV Calculated velocities, Summer 1915